The Royal Aeronautical Society

(FOUNDED 1866)

with which is incorporated The Institution of Aeronautical Engineers

No. 219. MARCH, 1929. Vol. XXXIII.

SIXTY-FOURTH ANNUAL REPORT OF THE COUNCIL, 1928-29

Council

President: Colonel the Master of Sempill, A.F.C., A.F.R.Ae.S.
Past President: Air Vice-Marshal Sir W. Sefton Brancker, K.C.B., A.F.C., F.R.Ae.S.
Vice-Presidents: Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O.
Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P.

COUNCIL—

Captain P. D. Acland.
Mr. M. L. Bramson, A.C.G.I., F.R.Ae.S., M.I.Ae.E.
Mr. Griffith Brewer, F.R.Ae.S.
Major J. S. Buchanan, O.B.E., A.M.I. Mech.E., F.R.Ae.S.
Wing Commander T. R. Cave-Browne-Cave, C.B.E., A.M.I.Mech.E., A.M.I.N.A., F.R.Ae.S.
Mr. A. E. L. Chorlton, C.B.E., M.Inst.C.E., M.I.Mech.E., A.F.R.Ae.S.
Mr. C. R. Fairey, M.B.E., F.R.Ae.S.
Captain F. T. Hill, F.R.Ae.S., M.I.Ae.E., B.Sc., Wh.Ex.
Captain A. G. Lamplugh, A.F.R.Ae.S., M.I.Ae.E.
Major A. R. Low, F.R.Ae.S.
Mr. W. O. Manning, F.R.Ae.S.
Major R. H. Mayo, O.B.E., F.R.Ae.S.
Lieut.-Colonel M. O'Gorman, C.B., D.Sc., F.R.Ae.S.
Mr. F. Handley Page, C.B.E., F.R.Ae.S.
Mr. T. O. M. Sopwith, C.B.E., F.R.Ae.S.
Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.
Mr. L. A. Wingfield, M.C., D.F.C., A.R.Ae.S.I.
Mr. R. McKinnon Wood, M.B.E., Assoc.M.Inst.C.E., F.R.Ae.S.
Honorary Treasurer: Major D. H. Kennedy, O.B.E., F.R.Ae.S.
Hororary Librarian: Mr. J. E. Hodgson.
Honorary Accountant: Mr. A. N. D. Smith, F.I.C.A.
Secretary and Editor: Captain J. Laurence Pritchard, Hon.F.R.Ae.S.
Assistant Secretary: Miss O. St.B. St. Barbe.

Committees of Council

The following Committees were appointed by the Council in 1928:—

Grading Committee.—Major P. Bishop, Mr. R. A. Bruce, Mr. R. S. Capon, Wing Commander T. R. Cave-Browne-Cave, Mr. A. E. L. Chorlton, Mr. F. T. Hill, Captain A. G. Lamplugh, Major A. R. Low, Mr. R. K. Pierson, Mr. W. P. Savage, Mr. R. V. Southwell, and Dr. H. C. Watts.

Finance Committee.—Mr. J. E. Hodgson, Major D. H. Kennedy, Mr. A. N. D. Smith, Mr. H. T. Tizard, and Mr. L. A. Wingfield.

Informal Discussions Committee.—Mr. M. L. Bramson, Major J. S. Buchanan, Mr. F. A. Foord, and Major R. H. Mayo.

Medals and Awards Committee.—Mr. Griffith Brewer, Major J. S. Buchanan, Mr. W. O. Manning, and Mr. L. A. Wingfield.

Joint Standing Committee with the Society of British Aircraft Constructors and the Royal Aero Club.—Mr. Griffith Brewer, Colonel the Master of Sempill, and Air Vice-Marshal Sir Vyell Vyvyan.

REPRESENTATIVES ON OTHER BODIES—

British Engineering Standards Association Aircraft Committee.—Major R. H. Mayo, and Dr. H. C. Watts.

Central Library for Students.—Mr. J. E. Hodgson (Hon. Librarian).

Students' Section.—Hon Secretary, Mr. H. F. Winny.

Association of Special Libraries and Information Bureau.—Mr. J. E. Hodgson (Hon. Librarian).

Membership

The membership of the Society continues to show a satisfactory increase. The new Rules, which came into force on January 1st, 1928, have worked, on the whole, very smoothly, although their practical application during the twelve months has shown that it may be necessary to modify them slightly. The object of the new rules was to stiffen very considerably the conditions for technical membership of the Society in order that such technical membership should be universally recognised as a very definite and real qualification.

In the following table is shown the figures of membership as on January 1st, 1929. The figures in brackets refer to the corresponding figures on December 31st, 1927.

Grade.	No. of Members.	Hon. and Life Members.	Suspended.	Total.
Fellows	95 (88)	16 (19)	2 (—)	113 (107)
Members	57 (73)	— (4)	3 (—)	60 (77)
Associate Fellows	330 (318)	5 (8)	14 (5)	349 (331)
Associate Members	97 (125)	— (9)	10 (—)	107 (134)
Associates	110 (111)	3 (3)	12 (3)	125 (117)
Companions	118 (129)	14 (16)	13 (3)	145 (148)
Founder Members	40 (45)	—	2 (—)	42 (45)
Students	101 (109)	—	11 (2)	112 (111)
Temporary Hon. Members	—	22 (22)	—	22 (22)
	948 (968)	60 (81)	67 (13)	1075 (1062)
Less Joint Members	28 (54)	—	—	28 (54)
	920 (940)	60 (81)	67 (13)	1047 (1038)
Branches—				
Coventry	231 (162)	—	—	231 (162)
Halton	2000 (1500)	—	—	2000 (1500)
Manchester	28 (31)	—	—	28 (31)
Yeovil	171 (130)	—	—	171 (130)
Australian	33 (45)	— (2)	—	33 (47)
Leeds	38 (32)	—	—	38 (32)
Oxford	30 (—)	—	—	30 (—)
	3451 (2844)	60 (83)	67 (13)	3578 (2940)

Amalgamation with the Institution of Aeronautical Engineers

Although the amalgamation between the Royal Aeronautical Society and the Institution of Aeronautical Engineers came into actual being on October 1st,

1927, its effect was not felt until the beginning of 1928. The Council have now had the opportunity of watching the working of the amalgamated body during a full period of twelve months and they wish to place on record their great gratification with the way in which everyone concerned has worked to make the amalgamation the success it is. The Council felt that when the agreement was reached in 1927 between the two bodies one of the greatest steps forward in the Society's history was taken, and the progress of the last twelve months has more than justified the hopes which were expressed at the time.

£10,000 Endowment Fund

The Council have been very disappointed by the lack of progress shown by the Endowment Fund. The Finance Committee have under consideration a scheme for trying to augment the Fund during 1929. The Council feel that the importance of making the Fund a really substantial one cannot be exaggerated in view of its objects. These are to provide a permanent building as the Society's headquarters and the provision of an income for its upkeep. The Council hope that all members will bear the Fund constantly in mind.

The Fund now stands at £1,047 18s.

Guggenheim Fund for the Promotion of Aeronautics

The Daniel Guggenheim Fund for the Promotion of Aeronautics made, for the year 1927, a grant of $5,000 to the Society. This grant gave a very great impetus to the work of the Society, and enabled the Council to carry out schemes to extend the scope and influence of the Society. In 1928 a second grant of the same amount was made, and in January, 1929, a third grant of $5,000 was received.

The Council wish to repeat and place on permanent record what they have already written to the Trustees of the Fund, their grateful thanks for these extremely generous grants. Such grants serve to emphasise the broad outlook of the Trustees of the Fund and the world-wide vision which they have in their administration of the Fund at their disposal.

Donations

For the fourth year in succession the Council record with great pleasure a grant of £250 to the Society by the Society of British Aircraft Constructors. A similar sum has also, for the fourth successive year, been granted to the Society by the Air Ministry. It is entirely owing to these grants that the Council have been enabled to enlarge very greatly the activities of the Society, and to push forward their policies for increasing the membership and disseminating technical information.

Library

For the fifth year in succession the Council have to thank Mr. J. E. Hodgson for the time he has given to the Library, and for acting in connection therewith as the Society's representative at the Council Meetings of the Central Library for Students and A.S.L.I.B.

During the year a number of cinematograph films and lantern slides were presented to the Library, and the Council wish to express their thanks to the following for their generous gifts:—

Messrs. Short Bros., Ltd.—Films and Slides.
Messrs. Vickers, Ltd.—Film.
Gloster Aircraft Company—Slides.
The Bristol Aeroplane Co., Ltd.—Slides.
D. Napier & Son, Ltd.—Slides.
Rolls Royce, Ltd.—Slides.

Awards

SOCIETY'S GOLD MEDAL.—The Gold Medal of the Society is the highest honour which the Society can confer. It has been awarded to the Brothers Wright, Mr. O. Chanute, Professor Bryan, Mr. E. T. Busk, Professor Lanchester and Professor L. Prandtl. No award was made during 1928.

1. THE TAYLOR GOLD MEDAL is awarded annually, at the discretion of the Council, for the most valuable paper submitted or read during the previous session.

The Taylor Gold Medal was awarded by the Council to Mr. R. K. Pierson, B.Sc., Assoc.M.Inst.C.E., F.R.Ae.S., for his paper on "The Use of the Wind Tunnel for Performance Prediction." The paper was published in the Journal for February, 1928.

2. THE SIMMS GOLD MEDAL is awarded annually for the best paper read in any year before the Society on any science allied to aeronautics, *e.g.*, meteorology, wireless telegraphy, instruments.

The Simms Gold Medal was awarded by the Council to Captain F. Entwistle for his paper on "Fog." The paper was published in the Journal for May, 1928.

3. THE SIR CHARLES WAKEFIELD GOLD MEDAL is awarded annually to the designer of any invention or apparatus tending towards safety in flying, and is open to members or non-members.

The Sir Charles Wakefield Gold Medal was awarded by the Council to Mr. F. Handley Page, C.B.E., F.R.Ae.S., for his work in connection with the Automatic Slot.

4. THE SOCIETY'S SILVER MEDAL is awarded, at the discretion of the Council, for some advance in aeronautical design.

The Silver Medal of the Society was awarded by the Council to Mr. B. N. Wallis for his work in connection with R.100.

5. THE R.38 MEMORIAL PRIZE is offered annually for the best paper received by the Society on some subject of a technical nature in the science of aeronautics, preference being given to papers which relate to airships. The prize is twenty five guineas.

The R.38 Memorial Prize for 1928 was awarded to Mr. H. Roxbee Cox, for his paper on "The External Forces on an Airship Structure with Special Reference to the Requirements of Rigid Airship Design." The paper will be published in an early issue of the Journal.

6. THE EDWARD BUSK MEMORIAL PRIZE is offered annually for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes (including seaplanes). Its value is twenty guineas.

The Edward Busk Memorial Prize was awarded by the Council to Mr. A. Fage for his paper on "Some Recent Experiments on Fluid Motion." The paper was published in the Journal for April, 1928.

7. THE ELLIOTT MEMORIAL PRIZE is awarded annually for the best essay submitted by an apprentice at Halton on a subject chosen by the Council which has reference to the work of the air mechanic.

The Elliott Memorial Prize for 1928 was awarded by the Council to Mr. C. V. Brown for his paper on "The Technical Problems for Long Distance Flying."

Medals and Awards

At a Meeting of Council held on December 11th, 1928, it was decided to adopt the following recommendation of the Medals and Awards Committee:—

That the year for awarding all medals and prizes should be from July 1st

to June 30th. In the case of the R.38 and Busk Memorial awards the dates for entry this year should be advanced from their present dates of September 30th and December 31st, 1928, to March 31st, 1929, and that the papers should be delivered to the Secretary by June 30th.

The Committee also recommended and the Council adopted the following resolution:—

That the Wilbur Wright Memorial Lecture should not be included in the lectures to be considered for the awards of any medals and prizes by the Society.

Lecture Programme

1928.

October 4th.—Mr. J. D. North, F.R.Ae.S., M.I.Ae.E., "The Technical Development of the Aeroplane."

October 18th.—Mr. H. Sutton, M.Sc., "Light Alloys and their Use in Aircraft."

November 1st.—Mr. W. D. Douglas, A.F.R.Ae.S., and Miss C. B. Pettifor, "The Testing of Adhesives for Timber."

November 8th.—Wing-Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., "Machinery Installation of R.101."

November 15th.—Mr. R. J. Penn, A.M.I.Mech.E., "Testing Aeroplane Engines in Flight, with Special Reference to Carburation and Carburettors."

November 22nd.—Major T. M. Barlow, F.R.Ae.S., "The Influence of Size on Weight of Aircraft."

November 29th.—Mr. F. Sigrist, A.F.R.Ae.S., "Production Problems."

December 6th.—Squadron Leader J. H. L. Hinkler, A.F.C., D.S.M., R.A.A.F., on his "Solo Flight to Australia."

Wilbur Wright Memorial Lecture

The Wilbur Wright Memorial Lecture for 1928 was delivered by Mr. F. Handley Page on May 30th on his recent work on the Automatic Slot. The lecture was printed in the August issue of the Journal.

The Meeting was followed by the Annual Council Dinner at The Athenæum, at which a number of distinguished guests were present. The dinner was made the occasion to send to Mr. Orville Wright an illuminated address signed by those present. A photograph of the address appeared in the August issue of the Journal.

Banquet to Mr. A. V. Roe

On June 8th, 1928, a banquet was given by the Royal Aeronautical Society, the Royal Aero Club, the Air League of the British Empire, and the Society of British Aircraft Constructers, in honour of Mr. A. V. Roe, and in recognition of his pioneer work on machines of his own design and construction, and of the great debt which British aviation owes him.

A full account of the dinner, together with the names of those present, was published in the Journal for July, 1928. The large attendance of members and guests was a record at any aeronautical function of a similar nature. The banquet was followed by a dance, at which H.R.H. the Duke of York, Patron of the Royal Aeronautical Society, was present.

Wright Anniversary Dinner

The President and Council held a reception and dinner on December 17th, 1928, in honour of the first flight by Mr. Orville Wright in the history of the world in a power-driven heavier-than-air machine. By the courtesy of Colonel Sir Henry Lyons, Director of the Science Museum, the dinner was arranged

beneath the original Wright machine now housed in the Science Museum at South Kensington. The chair was taken by the President, Colonel the Master of Sempill, and the function was made the occasion for the presentation of the Society's awards of the year. A full account of the reception and dinner, together with the list of guests, was printed in the Journal for January, 1929.

Students' Section

A number of successful meetings were held and visits paid during the year by members of the Students' Section.

The Inaugural Lecture before the Section for 1928-9 was given by Major A. R. Low, F.R.Ae.S., Member of Council, on November 23rd, on "Some New Points of View on Fluid Motion." The Chair was taken by Mr. S. Scott Hall, a former Honorary Secretary of the Students' Section.

The Council hope that all Students will make every effort to attend lectures and visits arranged on their behalf. During the visits the students have opportunities of studying the practical side of aviation which they would not otherwise have.

In November Mr. H. F. Winny, the Honorary Secretary for 1927-28, resigned and Mr. T. Tanner was elected the Honorary Secretary for the coming year. The Council wish to place on record their thanks for the work Mr. Winny did during the year.

Branches

This year the Council have received a number of inquiries for the formation of new branches, particularly from Bristol, Martlesham, Birmingham, and Hull. A new branch was formed at Oxford during the year. The Council realise the importance of forming branches and are prepared to offer all assistance within their power both in their actual formation and carrying on. The existing branches are in a very flourishing condition and the Council wish to place on record their thanks for the amount of time and energy which has been devoted to the branches by their Chairmen, Honorary Secretaries, and Committees. Visits have been paid by the President and the Secretary to a number of branches during the year. The following is a list of branches and their addresses:—

Coventry Branch: 21, Styvechale Avenue, Coventry.
Hon. Secretary: F. Meadows, A.F.R.Ae.S.

Yeovil Branch: Westland Works, Yeovil, Somerset.
Hon. Secretary: V. S. Gaunt, A.M.I.Ae.E.

Manchester Branch: 25, Plymouth Grove West, Manchester.
Hon. Secretary: I. Levy, B.Sc., A.F.R.Ae.S.

Leeds Branch: The University, Leeds.
Hon. Secretary: T. M. Naylor, A.R.Ae.S.I.

Halton Branch: Royal Air Force, Halton, Bucks.
Hon. Secretary: J. Haddon, A.F.R.Ae.S.

Oxford Branch: Oxford University Air Squadron, Manor Road, Oxford.
Hon. Secretary: Wing Cmdr. A. G. R. Garrod, A.R.Ae.S.I.

Australasian Branch: "Orontes," Clarke Street, Granville, N.S.W.
Hon. Secretary: Mr. T. D. J. Leech, M.I.Ae.E.

International Aeronautical Exhibition, Berlin

The Royal Aeronautical Society was represented at the International Aeronautical Exhibition held in Berlin on October 7th-21st, 1928, by an historical exhibit of a notable character. The exhibit was designed to illustrate, by means of a carefully chosen selection of rare books, engravings, drawings, manuscripts

and photographs, the gradual evolution of the idea and the practice of flight in Great Britain from the earliest down to recent times.

The preparation of the great amount of material available was in the hands of Mr. J. E. Hodgson, the Honorary Librarian, who not only devoted a great deal of time and energy to make the exhibit representative and worthy of Great Britain, but lent the Society a large number of valuable books and prints from his own collection. A full account of the exhibit was given in the Journal for November, 1928.

The Council feel that the Society owes a very great debt of gratitude indeed to Mr. Hodgson, for the vast amount of work which he gave so willingly to make the Society's exhibit the great success it was. The Council have reason to believe that the main object of the exhibit, viz., to maintain or advance the prestige of the Society abroad, was definitely achieved. Mr. Hodgson's advice, too, on the general preparation of the exhibit proved invaluable. The Society was most fortunate that its President, Colonel the Master of Sempill, was able to accept an invitation from the Committee of the Exhibition to give a lecture, as the British representative. The Council wish to place on record their appreciation of the unstinted efforts of the President in organising the Society's exhibit.

International Civil Aeronautics Conference, Washington

At the International Civil Aeronautics Conference held in Washington on December 12th, 13th and 14th, 1928, the following members of the Society attended as its delegates:—

Captain R. J. Goodman Crouch, O.B.E., F.R.Ae.S., M.I.Ae.E.
Wing Commander E. W. Stedman, O.B.E., F.R.Ae.S., Chief Aeronautical Engineer in the Department of National Defence, Canada.
Captain F. S. Barnwell, F.R.Ae.S.
Dr. J. C. Hunsaker, Hon.F.R.Ae.S.
Hon. Edward P. Warner, F.R.Ae.S., Assistant Secretary of the Navy for Aeronautics, Washington, D.C.

A paper was prepared for the Conference dealing with the following British Pioneer flights:—

The First Non-Stop Trans-Atlantic Aeroplane Flight, June 14/15, 1919.
England to Australia Flight, 1919.
Flight round Australia, 1914.
London to Australia and Return, 1926.
Survey Flight round Africa, 1927-28.
Light Aeroplane Flight to Australia, 1928.

International Aircraft Exhibition, Olympia

An International Aircraft Exhibition will be held at Olympia, July 16-27, 1929. At the invitation of the Secretary of British Aircraft Constructors the Royal Aeronautical Society have accepted the offer of a considerable amount of space for staging an exhibit similar to the one staged so successfully at the Berlin Exhibition of 1928. The preliminary arrangements are in the hands of the President, Colonel the Master of Sempill, and Mr. J. E. Hodgson, the Honorary Librarian.

World Engineering Congress

A World Engineering Congress will be held in Tokyo in October-November, 1929.

The general programme of the Congress was summarised in the Monthly Notice for January, 1929. The Council are arranging to appoint delegates to the

Congress and to arrange for the reading of papers, a number of which have already been submitted.

Publications

During the year the Society has continued its policy of reprinting important lectures. Since the last Annual Report the following reprints have been published:—

No. 27. "The Problem of the Long Range Flying Boat," by Major J. D. Rennie, A.R.T.C., Assoc.M.Inst.C.E., F.R.Ae.S.
No. 28. "Fog," by Captain F. Entwistle, B.Sc.
No. 29. "Modern Developments in Aircraft Instruments," by Major C. J. Stewart, O.B.E., M.I.Mech.E., F.R.Ae.S., M.I.A.E.
No. 30. "Experiments on Modern Airscrews at High Tip Speeds," by Mr. G. P. Douglas, M.C., D.Sc.
No. 31. "The Variable Pitch Airscrew," by H. S. Hele-Shaw, D.Sc., LL.D., F.R.S., and J. E. Beacham, B.Sc., A.C.G.I., A.M.Inst.C.E.
No. 32. The 16th Wilbur Wright Memorial Lecture ("Automatic Slot"), by F. Handley Page, C.B.E., F.R.Ae.S.
No. 33. "Notes on a Family of Similar Flying Boats," by C. Dornier.
No. 34. "The Use of Light Alloys in Aircraft from the Point of View of Corrosion," by H. Sutton, M.Sc., A.F.R.Ae.S.

A new List of Members was published in October, 1928.

Journal

The largely increased size of the Journal of 1927 has been maintained throughout the year 1928. In addition to the Abstracts of articles appearing in the world's technical Press and Scientific publications, which are printed by arrangement with the Air Ministry, abstracts and summaries of all publications received by the Society have been printed.

In January, 1929, the first of the new Monthly Notices were printed, replacing the Preliminary Notices. These Monthly Notices are inset in the Journal, and such matter as appears in them which should be placed on record in the bound volumes will be embodied in the Annual Report of the Council. These Monthly Notices bring the Journal more in line with the Proceedings and journals of other scientific and engineering bodies.

Technical Information Index

During the year a card index has been formed at the Society's offices, giving references to articles, papers and books on all aspects of the science of aeronautics and its allied sciences. The Index already contains some 20,000 references, and is being constantly added to. It is hoped, in time, to make it one of the biggest aeronautical indexes extant. A list of the official publications, technical papers, etc., covered by the index is published from time to time in the Journal.

Finance

The Balance Sheet and Revenue Account of Aerial Science Ltd. are published with this issue. The form in which the accounts are drawn up show an excess of income over expenditure for the year under review of £1,114 16s. 7d. This figure is reduced in the Balance Sheet by the deficiency of earlier years to £576 9s. 7d. The Council wish to point out that even this excess is entirely due to generous donations which have been received. Deducting these donations, which are in no sense permanent sources of income, but are entirely dependent

upon the goodwill of the donors, there is an actual loss on the year of over £600.

The Council therefore feel that every effort must be made to make the Society self-supporting. In this effort every member can and ought to assist by increasing membership and by the building up of a substantial Endowment Fund.

The First English Aeronaut

On October 25th the Bishop of Oxford unveiled a tablet (erected by private subscription) in the Church of St. Peter in the East, Oxford, in memory of James Sadler, the First English Aeronaut, who was buried in the churchyard. Earlier in the year the Society renewed the tombstone over Sadler's grave by way of commemorating the Centenary of his death. The initiative in these matters was due to Mr. J. E. Hodgson, the Honorary Librarian, and the Council wish to record their appreciation of his work, both as their representative and in his personal endeavours. Mr. J. E. Hodgson and Captain J. Laurence Pritchard attended the unveiling ceremony on behalf of the Society.

President

At a meeting of the Council held on May 8th, 1928, Colonel the Master of Sempill, A.F.C., A.F.R.Ae.S., was unanimously elected President of the Royal Aeronautical Society with which is incorporated the Institution of Aeronautical Engineers.

The Council and the Society owe a very great debt to the Master of Sempill. Since he was unanimously elected its Chairman in 1926, he has given an increasing amount of time to the work of the Society, and it is, undoubtedly, largely his untiring energy on its behalf, his constant thought for its welfare, and his great capacity for organisation, which has placed the Society in the influential position it now is.

Colonel the Master of Sempill has been Chairman and President during a period of transition and difficulty, and it has been due to his great tact and good judgment that so many of the difficulties facing the Society during the past few years have been so successfully surmounted.

Resignation of Mr. B. Woodward

During the year the Council received, with great regret, the resignation of Mr. B. Woodward, on account of ill-health, from his position as Honorary Solicitor to the Society. Mr. B. Woodward became Honorary Solicitor in October, 1912, and in that year drew up the Articles and Memoranda of Association of Aerial Science Limited, the private limited company which controls the finances of the R.Ae.S.I. The work Mr. Woodward did on behalf of the Society in those early years, his untiring energy, and his sound advice, have proved of inestimable value. From the day he was appointed, until a few weeks before his resignation towards the end of 1928, the Council had constantly to ask his advice on legal matters, and those connected with the new rules and various draft regulations, and that advice was most ungrudgingly given. The Council wish to place on record their deep appreciation of Mr. Woodward's services during the past sixteen years.

Honorary Solicitor

Mr. Lawrence A. Wingfield, M.C., D.F.C., Associate, who acted as Honorary Solicitor for the Institution of Aeronautical Engineers, was formally appointed Honorary Solicitor to Aerial Science Ltd. on October 16th, 1928. As a Member of Council his advice has for the past year been freely given on all legal matters.

(*Continued on page 174*).

AERIAL SCIENCE, LIMITED

Balance Sheet,

Dr.	£ s. d.	£ s. d.
To *Nominal Capital* —		
Divided into 20 Shares of 1/- each and 999 Shares of £1 each ...	1000 0 0	
,, *Capital Issued*—		
19 Shares of 1/- each		0 19 0
,, *Sundry Creditors*		590 13 2
,, *Subscriptions Received in Advance*		161 11 3
,, *Donation received in advance*		1026 13 11
,, *Carnegie U.K. Trust Grant for Purchase of Books*		500 0 0
Expended to 31st December, 1928	465 8 7	
,, *Endowment Fund*—		
Balance at 31st December, 1927	597 2 0	
Add—Donations received during year	450 16 0	
		1047 18 0
,, *Surplus*—		
Reserve Fund—		
Balance at 31st December, 1927	3236 12 9	
Add—Entrance Fees received during year	149 8 0	
	3386 0 9	
Income and Expenditure Account—		
Excess of Income over Expenditure for year to date	1114 16 7	
Less—Deficiency at 31st December, 1927	538 7 0	
	576 9 7	
		3962 10 4
		£7290 5 8

We report to the Shareholders that we have examined the Books of the Society, and having is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs, of the Society.

3, Frederick's Place, Old Jewry, London, E.C.2.
11th February, 1929.

Income and Expenditure Account

Dr.	£ s. d.
To Office Rental, Heating, Lighting and Insurance	356 17 4
,, Salaries	1001 2 0
,, Printing and Stationery	375 16 5
,, Postages, &c....	171 8 3
,, Office Expenses	122 12 8
,, Meetings	183 12 1
,, Journals, Pamphlets, Etc....	704 12 0
,, Library Expenses	18 14 5
,, Audit Fee	26 5 0
,, Income Tax	10 14 0
,, Presentations, Medals, Etc.	58 12 6
,, Berlin International Exhibition	144 9 5
,, Dinners and Receptions	21 4 2
,, Subscriptions Written off	87 4 0
,, Examination Expenses	1 4 0
,, Excess of Income over Expenditure for Year, carried to Balance Sheet	1114 16 7
	£1499 4 10

(The Royal Aeronautical Society).

31st December, 1928.

Cr.	£ s. d.	£ s. d.
By *Office Furniture, Printed Books, Bindings, Old Prints, etc.*, as at 31st December, 1927 (including Carnegie Grant—£465 8s. 7d)	835 13 6	
Add—Additions during year	73 5 0	
		908 18 6
,, *Stock of* JOURNALS, *etc.*		460 12 1
,, *Stock of Stationery*		13 0 0
,, *Sundry Debtors, including Subscriptions owing*		183 12 10
,, *Investments at Cost*—		
£3483 6s. 0d. 5% War Stock, 1929/47		3465 4 9
,, *Endowment Fund*—		
£1281 19s. 9d. 3½% Conversion Stock at cost	984 18 3	
Cash at Bank	62 19 9	
		1047 18 0
,, *Cash at Bank and in Hand*—		
At Bank...	1210 0 1	
In Hand...	0 19 5	
		1210 19 6
		£7290 5 8

obtained all the information and explanations we have required we are of opinion that such Balance Sheet according to the best of our information and the explanations given to us and as shown by the Books

(Signed) PRICE, WATERHOUSE & CO.

for the Year Ending 31st December, 1928.

Cr.	£ s. d.	£ s. d.
By Annual Subscriptions		2511 10 4
,, Interest on Investments	181 13 4	
,, ,, ,, Deposit	4 15 4	
,, ,, ,, Endowment Fund Investment (*Less Tax*)	27 15 0	
		214 3 8
,, Donations		1773 10 10
		£4499 4 10

During the progress of drafting the new rules for the amalgamated body, Mr. Wingfield's services were of the greatest possible value to the Rules Committee, of which he was a member.

Staff

The activities of the Society are increasing rapidly and such general progress as has been made is due in no uncertain measure to the unremitting activity of the Secretary and the Staff.

The Secretary, Captain Pritchard, who was appointed in 1935, has displayed considerable tact in carrying out his duties and has during past years at least served the Society under conditions that would not have been acceptable to anyone unprepared to place personal considerations in the background. The Council wish to emphasise and place on record their great appreciation of the work done by the Assistant Secretary Miss Barbe, Miss Jarvis and Miss Todd.

Honorary Treasurer

For the second year in succession the Council have to acknowledge the great debt they owe to Major D. H. Kenne[illegible] F.F.Ae.S., the Honorary Treasurer, for the constant advice and assistance he has given.

Honorary Accountant

The Council record with great pleasure the advice which has been given throughout the year by Mr. Norman Smith, the Honorary Accountant.

PROCEEDINGS

FOURTH MEETING, FIRST HALF, 64TH SESSION

In the Chair: THE PRESIDENT, COLONEL THE MASTER OF SEMPILL

THE MACHINERY INSTALLATION OF AIRSHIP R.101

BY

COMMANDER T. R. CAVE-BROWNE-CAVE C.B.E., A.M.I.Mech.E., A.M.I.A., F...

This was a joint meeting of the Royal Aeronautical Society and the Institution of Automobile Engineers, and was held in the Lecture Hall of the Royal Society of Arts, John Street, Adelphi, W.C.2, on Thursday, November 8th, 1928.

PRESIDENT: I have extended a hearty welcome to all present and particularly to the President of the Institution of Automobile Engineers (Mr. L. H. Pomeroy), whom he hoped would attend future meetings of the Society and the joint meetings which had been arranged. The joint meetings had been successful indeed in the past and he hoped that, in addition to those already been arranged for the present session, there would be future sessions.

The author of to-night's paper was one of two distinguished brothers who had done a very great deal indeed to bring the Royal Air Force to its present state of efficiency. The name of his brother Group Captain Cave-Browne-Cave would be recorded in history as that of the leader of the greatest and most successful cruise yet made by any aircraft in the world—the cruise of the flying-boat marine "Southampton" machines from this country to Australia and Singapore, and which was later being extended to Hong Kong and generally. A lecture by Wing Commander Cave-Browne-Cave always attracted considerable attention. He was intimately connected with the work of the Royal Aeronautical Society and of other kindred bodies, such as the Institution of Automobile Engineers, the Institution of Mechanical Engineers and the Institution of Naval Architects. His career had commenced in the Royal Navy; subsequently he had joined the Royal Naval Air Service, and for the last many years his time had been devoted almost exclusively to problems arising from the design and use of lighter-than-air craft. His design experience and general technical experience had been tempered with a great deal of practical experience in the operation of this type of craft.

There were differences of opinion with regard to the present airship policy, but he personally ranged himself very decidedly on the side of the airship enthusiast, because he believed the airship would prove to be the type of craft which would solve long-distance transport problems, he hoped in the near future. He looked forward to the time when the two great airships now being

built would take the air and [illegible] as many people believed they would do, that they were capable of doing [illegible] was expected of them in that direction. There had been much criticism [illegible] airship policy generally, and it seemed to him that much of it was [illegible] unjustified. He was perfectly sure that Wing Commander Cave-Brown-Cave and those associated with the building of both airships now under construction would be the first to welcome constructive criticism. Anything which was obstructive, however, and had no constructive element in it at all, was very much to be deplored.

Wing Commander T. [illegible] CAVE-BROWN-CAVE: It is the doubtful reliability of the machinery which more than any other factor has limited the use of past airships. It is the use of petrol which—apart from attack with incendiary bullets—has constituted the greatest fire risk in connection with their operation.

In developing the machinery installation of R.101, reliability and safety from fire have been the main objectives.

Safety has been sought by the use of heavy fuel oil instead of petrol. This was only possible in an engine developed by Messrs. Beardmore from a general type which weighed about 100lbs. per b.h.p. So long a step involves delay and uncertainty which, however, appeared justified by the gain in safety.

Reliability, although possibly prejudiced by the use of such a new engine, has been sought in the design of the installation and in the preparation made for test. Each engine is carried in a self-contained unit, which can be easily changed for another complete unit, while the airship is at the mooring tower. Each unit can therefore be mounted on a gantry and tested under conditions essentially similar to those of flight.

It was hoped that engines might have been available in time to allow a unit to undergo such thorough test and development that by the time the airship makes her trial flight they would cause no uncertainty whatever in the mind of the Captain.

In the following description the author has been allowed to cover not only the installation as it will be used in the trial flights, but also much of the experimental work which has led, through some changes, to this conclusion, and to outline developments which appear indicated for a later stage. It is more usual to describe only the successful achievement, and the author is most grateful to the Air Ministry and to the various firms for permission to follow what appears to him to be the more useful course.

It should be remembered, when considering questions of efficiency and economy, that the design is based on a normal flight of 50 hours.

The general arrangement of the airship is shown in Fig. 1. There are five identical power units of which the aftermost is placed on the centre line so as to give a good flow of air to the rudder, even at the low speed at which the airship will approach the mooring tower. The remaining cars are in pairs, some distance before and abaft the passenger quarters.

The choice of the number of units is limited partly by the engines available, but also by the power which can be efficiently used in an airscrew of reasonable size at the air speed of 75 miles/hour, a speed which is low by comparison with present aeroplane practice. Airscrew efficiency is of great importance because the design is based on a normal flight of 50 hours.

The design provides for variable pitch airscrews, capable of giving forward, neutral or astern thrust. Astern thrust is necessary to checking the forward way of the airship as she approaches the mooring tower. It would never be used to give the airship any actual movement astern.

It was originally hoped that each engine would develop 700 b.h.p. at 1000 revs./min. If fitted with a 16ft. airscrew, such units would have given a very satisfactory airscrew efficiency and a good airship speed.

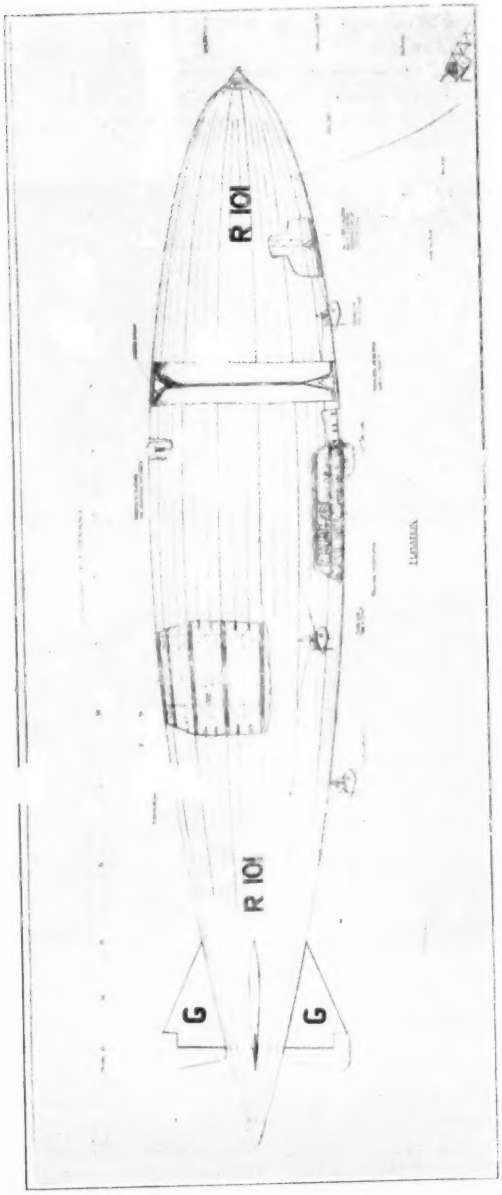


FIG. 1.

The Main Engines

The Beardmore Tornado engines are now to develop a continuous full power of 585 b.h.p., with a maximum of 650 b.h.p.

Their paramount merit for this duty is that they burn oil of such high flash point that it has to be heated to the temperature of boiling water before it will give off any inflammable vapour at all. The safety of this fuel is discussed more fully later in the lecture, but is mentioned here because it was the decisive factor in the choice of engines.

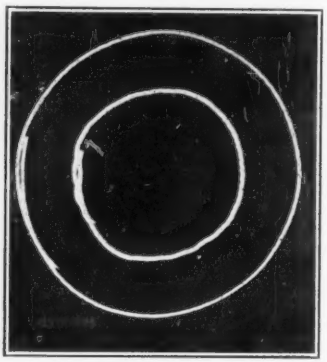


FIG. 2.

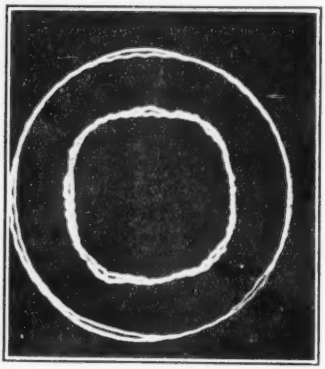


FIG. 3.

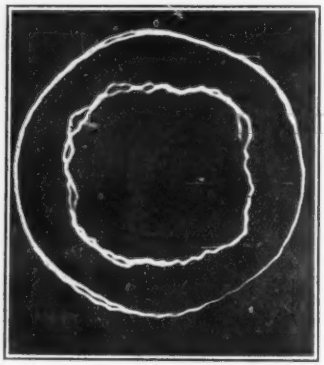


FIG. 4.

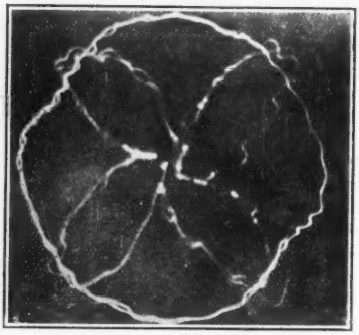


FIG. 5.

The engine has eight cylinders of 8¼in. bore with a 12in. stroke arranged upright in line.

This arrangement involves a comparatively long crankshaft which in association with eight cylinders is liable to suffer torsional resonance at a comparatively low speed.

This resonance has proved to be the greatest difficulty which has been met in the development of the engine. Although there were signs of it during the early tests on the Froude brake, the trouble could not be thoroughly investigated until the engine was run with its airscrew. The development further of the engine on the brake was done without flywheel and with a spring

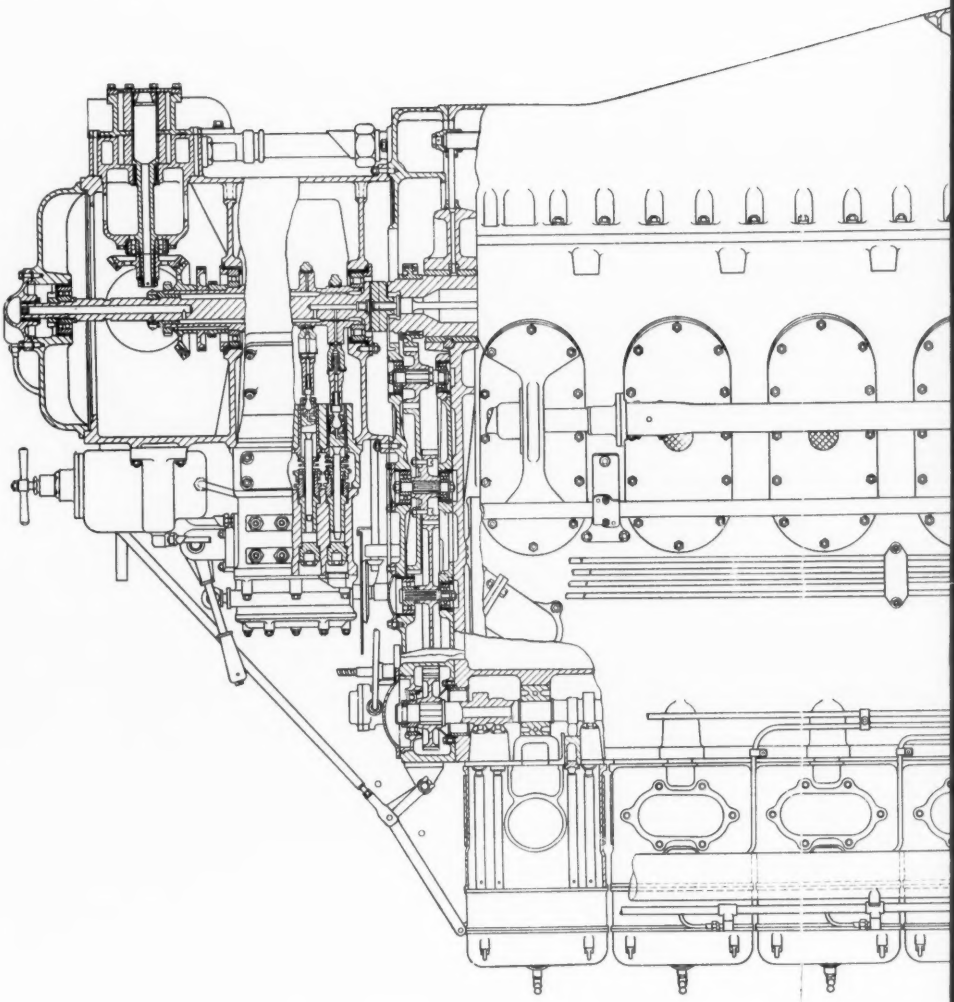


FIG. 6

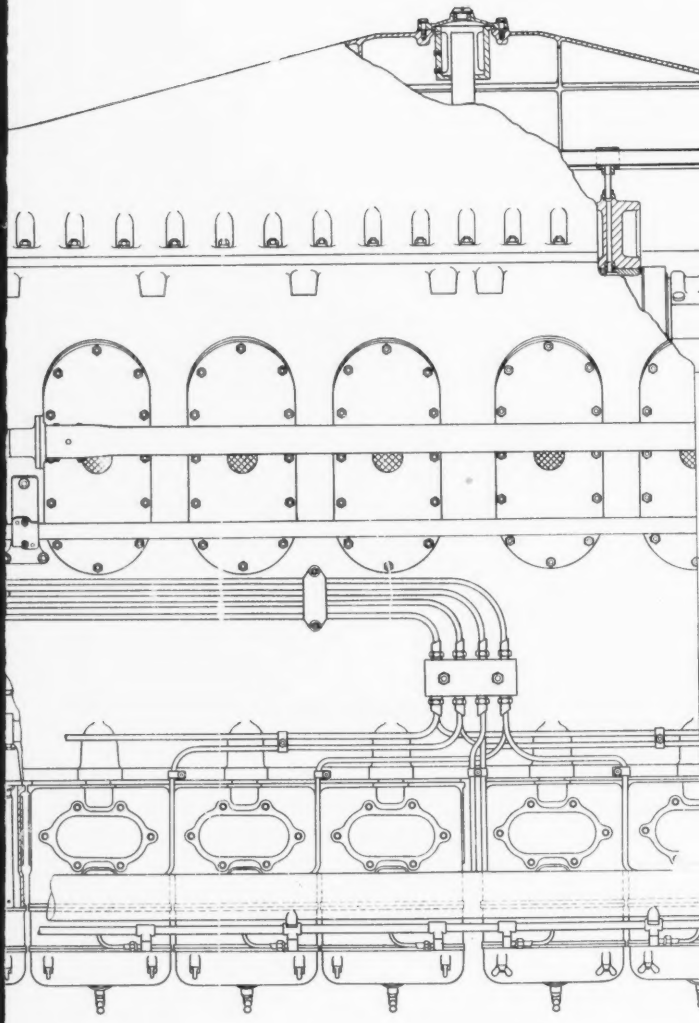
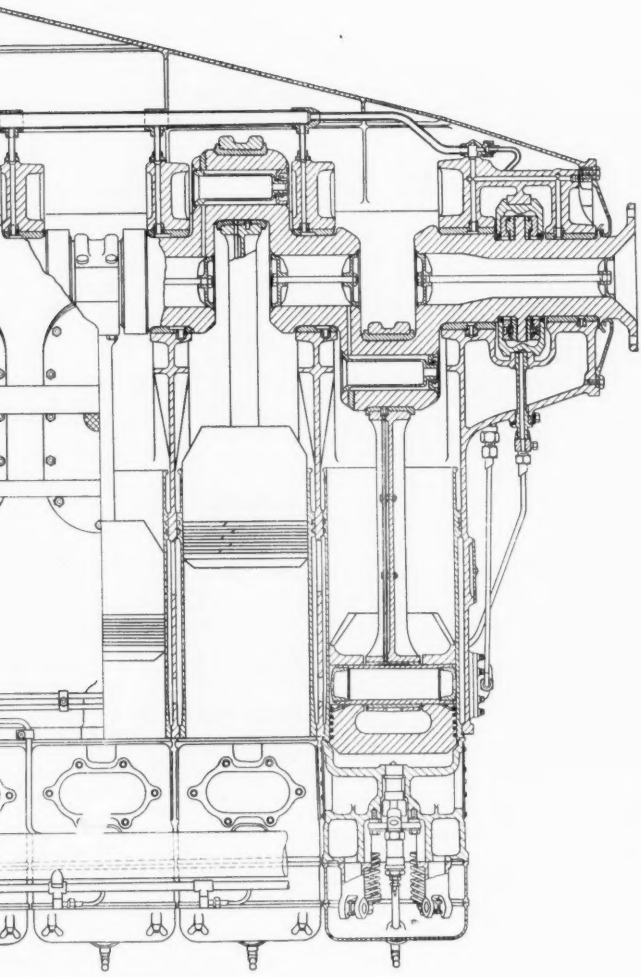


FIG. 6a.



coupling. R.A.E. carried out a static twisting test on the crankshaft, and from it estimated that there would be a major critical speed at 930 revs./min.

The serious trouble arose when the airscrew test began. It was investigated by the Staff of R.A.E. with a torsiograph (described in R.Ae. Journal of April, 1927), which recorded photographically the torsional strain produced in the crankshaft at each part of the cycle. The torque strain is measured by the polar ordinates. Figs. 2, 3, 4 and 5 reproduce diagrams taken at an engine speed of 450, 750, 850 and 950 revs./min.

The diagram for 950 revs./min. showed a variation of plus and minus thirty times the mean torque. This may have been an exaggeration by the instrument or an abnormally serious building up by resonance. The instrument, after it had been improved in detail, showed under similar conditions a variation of fifteen times the mean torque.

An eight-cylinder engine of this type will, without resonance, show a variation of about 75 per cent. of the mean torque. The effect of resonance was therefore to increase the variation to twenty times its normal value.

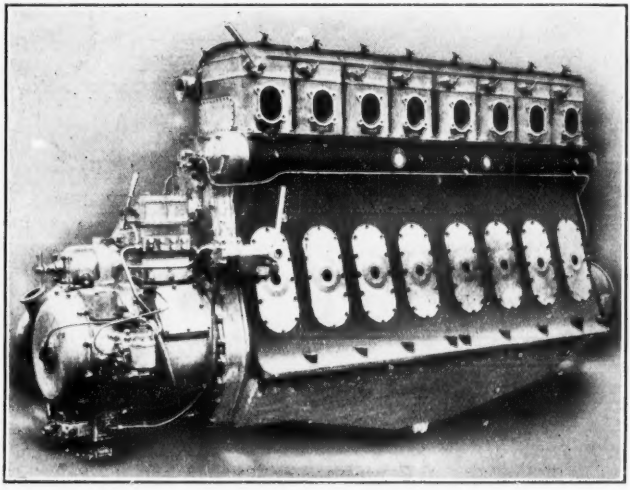


FIG. 6.

From research which he has now done on the shafts of this and another type of engine, Major Carter has evolved a formula (vide *Engineering*, 13 July, 1928, p. 36) whereby the dangerous resonant speed of a crankshaft can, with fair accuracy, be predicted from the drawings of the shaft.

It was, without complete reconstruction of the engine, only possible to increase certain dimensions of the crankshaft. New shafts have, however, been designed so far stiffer than the previous ones that the major critical speed is well outside the normal range of running speed. It is not possible, however, to keep clear of the minor critical speeds and a damper flywheel is being fitted to the crankshaft at the end remote from the airscrew. As a still more certain remedy, it has been decided to fit, between the crankshaft and the airscrew, a spring coupling of stiffness so calculated as to bring the major critical speed far below the running range. The damper is being retained as an easily adjustable means of suppressing any difficulty which may arise.

All these troubles appear as a serious disadvantage of the eight-cylinder in line engine. Many of them could have been avoided if present knowledge had been available when the engine design began. Against them must be set the very great advantage that a straight engine has for installation in a narrow car, where, as in an airship, good access to all parts of the engine is required.

The engine is shown in Fig. 6 and 6a, and is closely similar to one which has been more fully described by Mr. Chorlton to the Institution of Mechanical Engineers (Proceedings, 19 March, 1926). Oil is injected into each cylinder shortly before the top of compression when the temperature and density of the air are sufficient to produce ignition and rapid burning. Injection normally begins at a fixed angle before the top dead centre. The quantity of fuel admitted and therefore the power developed depend upon the time for which this injection continues. This is controlled by a lever used like the throttle of a petrol engine but acting more like the cut-off of a steam engine. It constitutes the only "control" the engineer has to operate when varying power.

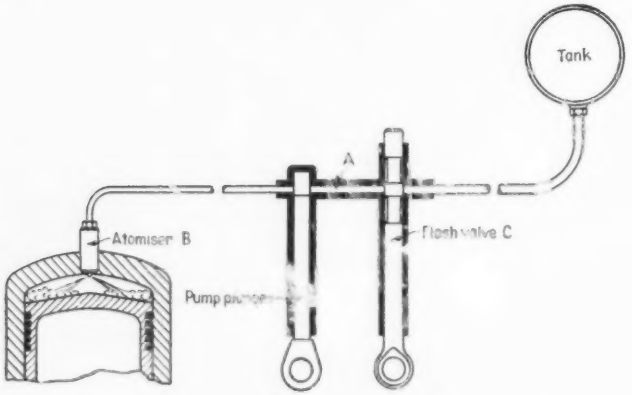


FIG. 7.

Its action is shown in Fig. 7. Injection only takes place while the belt on the flash valve closes the passage from the fuel supply to the pump. One edge of this belt is square to the axis and causes injection always to begin at the same point of the stroke. The other edge is in a plane inclined to the axis. When it opens the port injection ceases. Control is therefore effected by rotating the flash valve about its axis.

The sprayers are automatic and are actuated by the pressure produced by the injection pump. Each is mounted in the centre of the cylinder head between the two inlet and two exhaust valves.

The consumption of the engine at its continuous full power is .385lbs./b.h.p. per hour. This is a saving of some 30 per cent as compared with a petrol engine. Whereas the economy of a petrol engine decreases at lower power or if the altitude control is not most carefully used, the consumption of this engine improves slightly for a small decrease of power and is not endangered by the use of a difficult control.

The engine weighs about 8lbs./b.h.p. but there is reasonable doubt that this weight can be halved when the design has undergone the refinements necessary to bring it in line with other engines. There appears no fundamental reason why the weight of a compression ignition engine should

be as much as twice that of a petrol engine of the same power and equal refinement.

It must be remembered that none of the major troubles has been due to the engine working with heavy oil.

Engine Starting

The Tornado is started by an auxiliary engine which drives a Bendix pinion through a reduction gear of 20:1. Although the auxiliary engine is capable of developing over 40 h.p. at 2,000 revs./min., it is found that less than 10 h.p. is required to run the main engine up to the 100 to 120 revs./min., at which it starts without hesitation. A decompressor lifts an inlet valve of each cylinder and therefore prevents the fuel charge being fired. The main engine is driven at about 100 revs. by the auxiliary engine until fuel is being steadily delivered to every sprayer. The speed is then increased slightly and the decompressor shut. The momentum of the airscrew is quite sufficient to carry the main cylinders over full compression, thereby causing the injected charges to fire.

The Bendix pinion is thrown out automatically and closes an electric contact, thereby switching off the starting engine.

Variable Pitch Airscrews

The airscrew hub is of a design made to meet the requirements peculiar to airship use. The blades can be turned about their own axis so as to give ahead or astern thrust or into a neutral position where, although the engine is running and therefore instantly ready, no thrust is being developed.

This involves a movement of about 20° on either side of the neutral position. If, when the engine is stopped, the blades are turned through about 90° from the neutral position, they exert minimum drag.

If, while the airship is going ahead, the blades are gradually turned from position, they form a windmill by which engine can possibly be started.

Each blade root is with a fl innermo This engages a corresponding shou e full speed there is between these a pressure of some 40 tons, which ch blade very rigidly against rocking in its housing or gr ual variatio pitch.

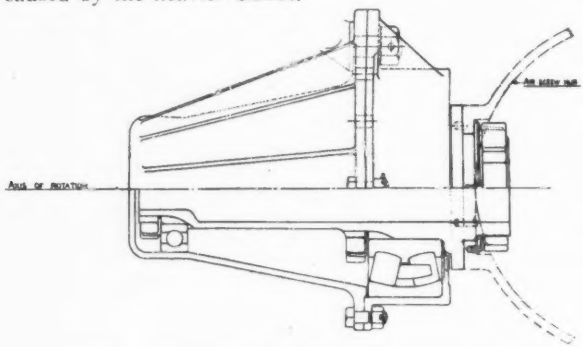
There is, howev a remely stiff sprin in the form triple Belleville washer, which when ed is decreased 500 overcomes the centrifugal force and releases the flange fro the de thereby allowing the blade to be fre rned by gearing.

The actuating gear the form of gage a wheel on eac ade root. actuated d bevel gearing by a ing carri on this gear ring the su of ep cyclic ge , although the airsc be rotating it s rned by a pinion the operating shaft w ns along the de of the engine. This e g, although it runs e engine, is under no load except when pit is actually being changed.

The hu ave proved entirely satisfactory unde nin test and prolonged tests in the car, mounted on the test gantry.

The air rew blades used with this hub were o el construction, which proved satisfactory on spinning t and on g in the car. They failed, however, during a torsiograph test in which th e exposed to altogether abnormal torque fluctuations referred to abo not possible greatly to increase the strength of blad f this des is necessary

still to provide against possibly large torque fluctuations, it has been decided to use solid alloy blades, on which the root strength can be greatly increased. These can be carried in the present hubs, modified to allow for the greater centrifugal force caused by the heavier blades.



THRUST WIRE BEARING.

FIG. 8.

As a temporary precaution against delay in developing these blades and the modified hub, wooden airscrews of fixed pitch are being constructed. One of these is being designed for astern thrust and is therefore capable of exerting the necessary thrust on the airship.

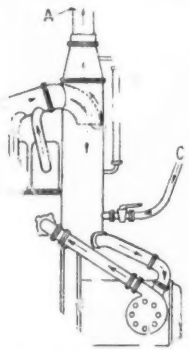
Thrust Wire

To ...vide for ... support of the p... r ... even when the airship is ...ached s... and the engines ... full power, it has ... found ne... ...st wire ... a b... ...rried on the ...ater fac... ...e airsc...

Such an a... ... before, but t... ...ly with ... geared airscrew shaf... ...ch the te... ...n member could ...e taken with a plain ... ...r end. I... th... present design the airscrew is carrie... ... the statior... cent... tension member is not possib... ...ore be capable of t... ...g the full tension of the wire ... ...t and a je... ...l b... ...ing which cannot be lubricate... ...nd 8*a* sho... ...ev... ...n ar...angement which, wh... ...roved entire... ...ausf... ...ry u...der large overload... ...al load.

Evapor...

The ... ... sy...er ...ich as already been descri... *...nn al*, J... 1926). The circulation of w... ...n Fig. 9 ... passes from the head



9.

..., which will, it is hoped, finally take the ... cover of the airship so that cooling ...g. Very satisfactory preliminary ex... ...ts, b... ... the step from the test house ... ... system should b... allowed to ... ...are therefore being provided for use ... tested in ...ight. Each radiator has a ... steam if the cooling is inadequate while

...ic'ship e... ...es is led to a large radiator ...c... ...arge o... ... ventilating fan of the ... ... required, ca... ...lowered into the ext... ... ...e liable t... ...eze. Steam may the ... ...angular form is ...factory.

... high enough for the condensate to ... ... thence to the engine. The passenger

radiator is, however, ne essarily below the level of the cars which supply it. An electrically driven pump is therefore mounted on the bottom of the radiator to return the condensate and to keep a pressure slightly below atmospheric, thereby assisting the flow of steam from the engine through the long lengths of piping.

Exhaust Boiler

The waste steam from the cylinder jackets cannot be at more than atmospheric pressure with the condensers connected to the cylinder heads of the Tornado engine. (This system would not be applicable in a redesigned engine). Some cooking processes require temperatures of fully 100°C and this would not at altitude be certainly available from water at atmospheric pressure.

It was therefore intended to supply steam at 50lbs./in.² pressure from an exhaust heated boiler.

It has subsequently been decided to abandon the whole of the cooking electrically. The design of the boiler which underwent satisfactory trials was interesting.

The tube block was built up like a honeycomb radiator from circular tubes opened out to hexagon ends and edge welded together. The tube block is contained in a cylindrical shell. There is an additional wrapper plate which fits close round the tube block but does not extend to the top or bottom ends. The formation of steam in the tube block therefore causes a violent circulation over the top of this wrapper plate.

The weight of the boiler empty was 153lb. It had 60 sq. ft. of heating surface and held 4 gallons of water to working level. It was pressure-tested to 500lbs./in.². An engine having 4 Tornado cylinders and developing 270 b.h.p. with a fuel consumption of 1.25lbs./b.h.p./hr. passed exhaust gas to this boiler at 600°F. and evaporated 6lbs. of water per minute at 50lbs./in.² pressure. The back pressure in the exhaust manifold was 0.25lbs./in.²

As a precautionary measure the supply of feed water was stopped to see the boiler run dry without any ill effects of overheating.

The boiler could not be opened for examination except by cutting out the whole of the shell plate which would be replaced by a section welded in.

In the experimental boiler there was comparatively little scale, but serious corrosion. Subsequent boilers were therefore to have been made of stainless steel, which it was found could be satisfactorily welded in the ways required.

An alternative type of boiler was simultaneously tested. In this the steam was discharged over water tubes. The tubes had, for reasons of space, to be horizontal and it proved impossible to achieve steady circulation without priming. There was great difficulty in supporting the external casing against the pulsations of the exhaust. This design was abandoned.

Auxiliary Machinery

The auxiliary engines are required, in addition to starting the main engines, to drive electric generators and air compressors.

Three engine cars carry electric generators and the remaining two air compressors. These are mounted on slide rails under the auxiliary engine, so that they can be moved aft for examination or a generator and compressor interchanged.

A constant speed windmill is mounted coaxial with the auxiliary engine and can drive the auxiliaries when the airspeed is above 40 miles/hr. It maintains constant speed under 100 per cent. variation of load and between airspeeds of 40 to 80 miles/hr. It develops 12 to 15 h.p.

Pitch is varied by t[illegible]n heavy cups, carried on arms attached to the blades, ac[illegible]stable [illegible]ings. The movement is damped and the blades [illegible]e in un[illegible] link attached to a dashpot at the front end of t[illegible]

The engines at present ins[illegible] petrol, but one supply in each car is carried in a tank which can [illegible]e slipped in case of fire.

The cooling water system of [illegible]liary e[illegible]ined up with that of the main engine, so that no inde[illegible] radiat[illegible]s r[illegible]ed. The auxiliary engine can warm the main engine. [illegible]gh that ha[illegible]roved necessary for starting it may be a [illegible]venient way of [illegible]ing freezing [illegible]hen the main engine is stopped.

Lubricati[illegible] Oil System

The lubri[illegible]g oil is carried in two [illegible]ks [illegible]n bays of the car structure [illegible] th[illegible] forwar[illegible] end of the e[illegible]

The la[illegible]er [illegible] fitted with [illegible]o [illegible]paratively small quan[illegible] of oil [illegible]l circulatio[illegible] [illegible]m up quickly. There [illegible]re, howe[illegible]les through top [illegible]ne baffle sufficient to allow oil to pass [illegible] circulation as req[illegible].

The second tank [illegible]s suction and deliv[illegible]om the engine, so that it forms a storage and an alternative avail[illegible]se of failure of the larger tank.

There [illegible] a cock on the suction and [illegible] delivery pipe of the oil pumps, so that th[illegible]hange over can be quickly effected. These cocks are so shaped that they [illegible] not, at the risk of [illegible]sting [illegible]e pump, be wholly shut off while changing [illegible]er.

The full quantity of oil re[illegible] for 5[illegible]urs flight can be carried in these two tanks. The difficulty of [illegible]g oil fro[illegible] a storage in the hull is therefore avoided.

The heat [illegible] a t[illegible]ngine gives to its oil is large as compared with th[illegible] in [illegible] aero[illegible] [illegible]he same power. This is presumably because of the [illegible]ge su[illegible]ace [illegible] th[illegible]ase kept at almost 100°C. by proximity to the cylinder jackets. Th[illegible]atted surface in the crankcase is, however, correspondingly large (abo[illegible]oft.²). The air in the crankcase is circulated violently over this large sur[illegible] and rapidly reaches the temperature of the oil. Circulation of air through the crankcase is therefore a very effective method of oil cooling. It is necessary however, to prevent the passage of oil with the issuing air. It was proposed to draw the whole of the induction air through the crankcase and a satisfactory apparatus was made for the experimental engine, which had four Tornado cylinders. The slight loss of pressure and increase of air temperature had no measurable effect on the power or fuel consumption.

In avoiding the loss of lubricating oil the greatest difficulty lay in preventing a film [illegible] oil being swept up the pipes and sides of the separator chamber by the flow of air. As soon as the nature of the trouble was detected, it was easily avoided by making the tank wide enough to give a [illegible]y low air velocity over one section. Drops of oil were easily stopp[illegible] by suitably shaped intakes. The oil fog which is sometimes visible from crankcase vents appears to contain a totally negligible volume of oil.

Some doubt was raised as to the safety of the apparatus from explosion, and as the risk could not be wholly disproved, the system was abandoned in favour of the conventional Potts oil coolers, which, however, involve some drag and a considerable amount of piping external to the engine.

The system is, however, worth consideration, but the suggested danger is here explained so that it may be investigated by anyone interested. It was

suggested that if the inlet valves were opened by the decompressor while the engine was firing, a flame might ignite an explosive mixture coming from the crankcase. The total quantity of oil lost by the engine, only part of which ever entered the oil cooler, was 2.5 per cent. of the weight of fuel burnt. This quantity, if wholly vaporised and mixed with the air used by the engine, would give a fuel/air ratio of 0.13 per cent. by weight. This is about 1/40th of that given by Ricardo as the weakest mixture which can even, when compressed, be ignited, even by an electric spark. If the engine were re-started after having stood hot for a time, it is possible that the mixture in the crankcase might be stronger.

The danger, in so far as it exists at all, must be assessed in respect of any particular installation for which it may be considered.

It has not been adopted for the Tornado engine in R.101.

Accessibility and Repairs

An important respect in which an airship engine installation differs from that in other aircraft is that an engineer is on watch in each engine car and that an engine can, if necessary, be stopped for repairs in flight.

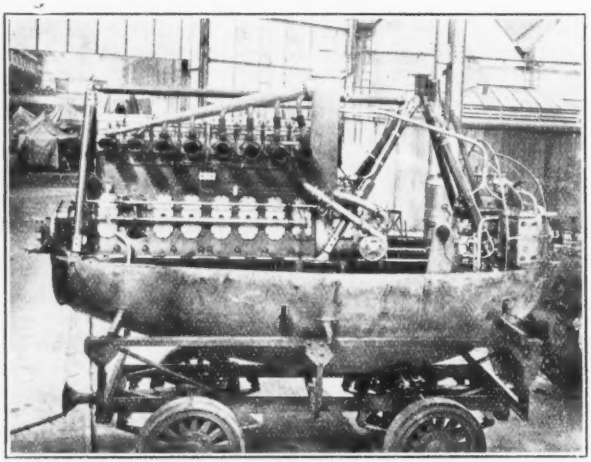


FIG. 10.

In the design of the installation proper attention must be given to accessibility, so that those minor defects which form such a large proportion of the causes of engine failure may be detected early and remedied, and so that even repairs of considerable magnitude can be effected in flight.

The car is shown in Figs. 10, 11 and 12. The engineer is entirely protected from the passing air and from a great proportion of the airscrew noise. The external shape of the car is, with the exception of the upper part of the engine, which necessarily protrudes at the after end, fair enough and small enough to satisfy all but the most exacting aerodynamic enthusiast. The maximum diameter of the car is less than half the diameter of the airscrew.

The engineer can, however, pass along the full length of both sides of the engine and reach any pipe or joint under the engine. There are on the port side two hatches which he can open and gain free access to the whole of the top and even the starboard side of the engine, while himself well protected from the

passing air stream. It is possible, in flight, to remove a cylinder head, piston and connecting rod.

In order to reduce as far as possible the time taken to remove engines for thorough overhaul, it is being arranged that the complete engine car can be

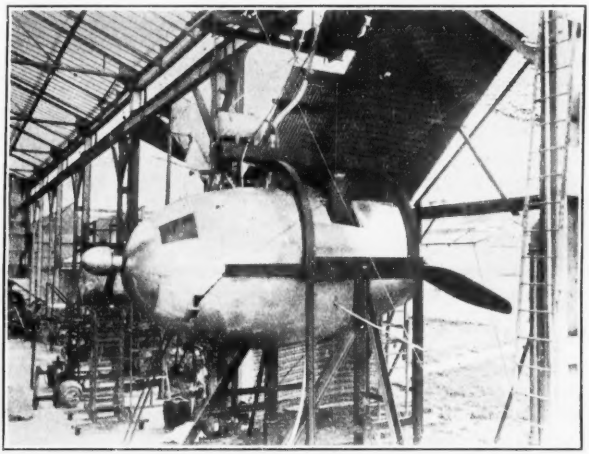


FIG. 11.

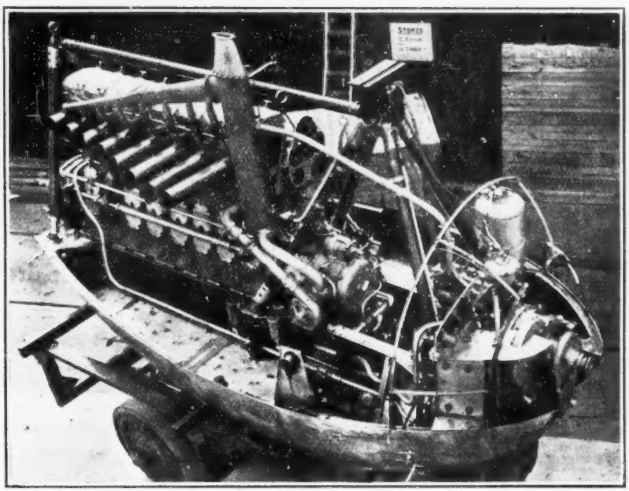


FIG. 12.

changed for a spare one while the airship is at the mast. This enables the complete unit, including its auxiliaries, piping, airscrew, etc., to be thoroughly tested on a gantry before installation in the airship.

It has the further important advantage that as soon as an improved type of engine is available, a power car can be developed for it so as to replace the earlier type of car without delay or alteration to the ship.

Gantry Tests

The first car with its main engine and auxiliaries installed has been mounted on a gantry and is suspended as it will be in the airship. Another engine and airscrew has been mounted ahead of the car and run so as to give an airstream of 70 miles/hr. over the whole car.

The car has been tipped 15° up and down, and the installation as a whole tested as thoroughly as possible with, however, the important reservation that, as this engine at present has a crankshaft of the old type which resonates at 950 rev./min., the speed must not exceed 750 revs./min. The power is therefore only about half the maximum.

It has lately been possible to increase the airscrew torque to its full speed value, so that at 750 revs./min. 75 per cent. of full power is being developed.

Fuel Storage System

The fuel storage system in the hull has not only to provide a supply of fuel to every engine car, but must make it possible to move large quantities of fuel fore and aft in the ship, to alter her trim and also to discharge fuel as ballast in case of emergency.

The storage tank unit is one of 224 gallons, with a clearance volume of 10 per cent. At certain positions it is more convenient to arrange this in two tanks of half the capacity, which are used, however, as one unit.

From the storage tanks fuel drains by gravity to a transfer tank, from which it can be blown by compressed air to feed tanks situated above each engine car, or, for altering the trim of the airship, to another storage tank.

Above each engine car are two feed tanks, each holding 224 gallons, but with 10 per cent. spare capacity, so that before either is empty it can take the contents of a storage tank. Each of these two feed tanks therefore holds sufficient fuel for its engine to run eight hours at normal full power. There is at the bottom of each feed tank a steam box by which the oil can be heated to flow down more easily to the engine car. The duplicate pipes down to the car run parallel to the steam pipes, so that there is little risk of failure of the oil supply, even at temperatures below 0°F., at which the oil will flow satisfactorily without any heating.

The capacity of the system is 29 tons, which leaves a considerable margin above the 22 tons which is required to reach Egypt by the longest of the three selected routes in 40 hours at an air speed of 76 miles/hr. against an average head wind of 15 miles/hr. Tanks are provided adjacent to the passenger space in which a further eight tons can be carried when a reduced weight of passengers and freight is taken.

Compressed air is supplied from a compressor in each of two engine cars, and is stored at 60 lbs./in.^{2} in a tank in the hull. This air storage and the transfer tanks are the only ones exposed to pressure.

Compressed air is used in the same way for trimming water ballast.

The system is filled through a 2in. main from the bow of the ship, and this same large pipe is used for moving fuel fore and aft for trimming.

In earlier airships it has been customary, when necessary to discharge ballast in emergency, to drop complete tanks containing fuel. These falling tanks, although satisfactory when raiding an enemy country, might in peace be described as a public danger. It has therefore been arranged that fuel can be released very rapidly from certain selected tanks fitted with special jettison valves. This allows the tanks to be slung far more conveniently than would be possible if they had to drop clear through the bracing wires and structure of the rings in which they are mounted.

A well-shaped 12in. orifice is formed in the bottom of the tank and sealed by a disc of 28-gauge aluminium. It has been found to stand an internal pressure of 40 lbs./in. as compared with the 2.5 lbs./in. to which it is exposed when the tank is full. Beneath this disc is a ring carrying seven knives, which, when the ring is rotated, rise into contact with the disc and cut it neatly out, releasing the fuel as a steady 12in. stream which falls clear through a short trunk to the outer cover, from which a sealing patch has been previously pulled off.

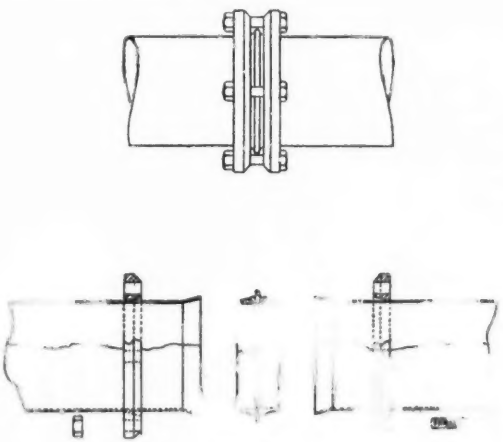
It takes eleven seconds to complete the whole operation of releasing the 224 gallons. A large vent is therefore necessary to admit air. In the first experimental tank the vent was too small and the tank collapsed.

The discharge is a smooth stream of fuel which does not break up in the airstream sufficiently quickly for spray to be thrown on to the outer cover. It is, however, interesting that when released from 250 feet, this stream has broken up to the equivalent of heavy thunderstorm rain before it reaches the ground, and if released from the height at which airships will normally fly, will almost certainly be undetectable and certainly so widely dispersed as to constitute no danger.

Pipe Fittings

The fuel oil is as " penetrating " as paraffin, and as it does not evaporate at all, leakage would be very objectionable.

The fuel pipes in the hull total a length of over 1,500 feet, the water pipes over 500 feet, and there are over 100 cocks. The pipe joints and cocks have therefore presented difficult problems.



13.

The pipe joint, Fig. 13, is a development of the oil [illegible] it instead of screwed nipples which would be [illegible] ra[illegible] flanges with steel bolts and nuts are used to draw [illegible] n[illegible]pe ends on to a duralumin double cone.

These joints have been subjected to [illegible] under rapid vibration while exposed [illegible] internal paraffin pressure [illegible] lbs./in.

The pipes burst before [illegible] under pressure test; the $\frac{3}{4}$in. bore at 85 lbs./in., the 3in. bore at 42[illegible]

Perhaps the greatest proof of their tightness is that under the whole fuel system as it is installed in the airship full of fuel, there are, with very few exceptions, no drip marks on the floor where a leakage has ever been.

Plug cocks have proved to be the most satisfactory and easily operated, but it has been found desirable, particularly in the 2in. size which have to withstand 60 lbs./in. when trimming, to arrange that the plug is lifted off its seating as it is turned. This is done in the large cocks by a separate grip blade on the plug and in the smaller size by pressing the handle.

Another fitting, though used in the steam pipe system, should be described here. The expansion joint shown in Fig. 14 though simple, has proved entirely satisfactory under a test pressure of 300 lbs./in. It is intended to be used in the pipe systems between the engines and condensers, which will be at almost atmospheric pressure.

It is made by spinning in aluminium pipe 20-gauge. The asbestos tape is a continuous spiral put in with graphite grease.

The external hose clip was intended to compress the aluminium tightly the correct diameter. Although the clip, which was of the Jubilee type, was strong enough to produce a reduction of diameter, no difficulty was found in making the pipe ends sufficiently accurate and the clip has been abandoned. If a clip is to be used, it is preferable to form the recess for the tape on the outer instead of in the inner pipe.

Fuel Specification

The fuel oil used has been to the specification given in Appendix.

This was drafted with the assistance of several firms and is a compromise between our requirements of low ash content and low pour point.

The airship may, even on a passage over England in mid-winter, be exposed to temperatures below 0°F. for a period of eight hours. The capacity of the feed tanks provides for double this period, and the supply from them can be steam heated.

Flow tests of various samples were carried out on a representative system of pipe valves and filter mounted in the cold chamber at R.A.E. They showed that most oils which have the viscosity specified will flow quite sufficiently rapidly through the system at temperatures down to 0°F.

The safety of a fuel may be measured by the difference between its flash point and the temperature of the hottest surface over which it can be

s difference indicates the rate at which in a vapour is given off, and therefore the best measure of the ri plosive mixture in a s il engine car.

Presumably the exhaust pipe is so arra ged that t ot reach it.

surface of the engine is th portance; much of it ma t almost 212°F.

t of the oil samples had a fla point of 21 we in that respect g ly preferable to those having 1 F.

The requirements of high flash p and l setti poi , unfortunately, agonistic. It is just those fractio of th which are capable of keeping the wax in solution which also reduce flash point. The sh point called for in the specification as temp y fixed at 180°F., in order not to restrict the sou es of supply, but most o s submitted ve had flash points from °F., and therefo h decided to raise the specified flash po t to 21 .

It may, however, be necessary er on to accept a l ash point in fuel intended for use in aeroplanes exp s to ve ow tem e. It would be possible and safe to hea he fuel y steam n porar ely cooled system, but with an air-cooled en e heating would me difficulties.

Water Recovery

It is unnecessary to add much to the the ture printed in the Journal for January, 1926. was there sh own ov atly he possible recovery depended upon the atmospheric humidity, and temperature to which the haust gas could oled.

What app satisfactory means e since been found for dealing with the dirt and the xhaust, olin the g to 100°C., at which temperature it ca seo to fabric ducts.

The apparat be install early flights of the airship, as its final design dep uch on the g obtainable from fabric ducts, and this can only b tain tisfactorily fro xperiments made in flight. This will be measure e tance for t acts used for evaporative cooling.

For a co mer it does not ap ar economically sound to fit re very apparatus sole f pose of reducing the quantity of hydrogen w must be replac ach voyage.

paratus capable overing, say, 30 per cent. of th el weight would the water req as ballast during the later sta of the flight. It ecrease the am nt of ballast and increase the amou f fuel or freight with which the airship could leave.

If, h , only part of t fuel weight is recovered, there must be a considerable ity of hydrogen hich will have to e discharged to restore the uilibriu th ship w landing. If this can be burnt as fuel, not only s it stil ue ity of oil which must be carried for a given age, but ake a ry so much easier from those engines in which it is burnt, t appara qu reasonable size is likely to be satisfactory.

Hydrogen Auxilic

Experin nts made e xperimental engine which had four Tornado cylinders sh that hyd en introduced with the air, can be burnt with fuel oil in so hig a proportion that a e gas wh h becomes available from the se of oil in ve engines can be bu , with oil, in two engines. This effects a ing of about 20 per cent. of the al required for given power.

It is co[illegible]venient bec[illegible] se onl[illegible] [illegible]e be [illegible]tt[illegible] recovery app[illegible]aratus, an[illegible] [illegible]dins a [illegible] proportion of steam and [illegible]

A necessary step in t[illegible] [illegible]e [illegible]lo[illegible] [illegible]sig[illegible] and t[illegible] [illegible] stopper to prevent the pa[illegible]g[illegible] [illegible] exp[illegible] proportions.

It is, unfortunately [illegible]ot [illegible] [illegible] thi[illegible] ev[illegible] protection for it i[illegible]ly [illegible].

Its effecti[illegible] [illegible]as be[illegible] [illegible] [illegible]y [illegible] i[illegible] [illegible]st exacting tests v[illegible] ha[illegible]r [illegible]

The lat[illegible] pa[illegible]g[illegible] [illegible] [illegible] [illegible]eal[illegible] [illegible] deve[illegible]opments which, although th[illegible] nav[illegible] [illegible], [illegible]ach [illegible]tiga[illegible] [illegible] [illegible]perimen[illegible] preparatory to their eventual inclusio[illegible] in [illegible]re., will not be in[illegible]led until the first vital parts of the power installation have been thoroughly proved in flight. It is, however, correct to include them, because they have been kept clearly in view throughout the development and are definitely considered to be advances tending to improve the economy with which the airship will operate.

Gaseous Fuel

Though, not, in the author's opinion, likely ever to be used in R.101, gaseous fuel should perhaps be referred to because it has been very carefully considered, so far as information was available, and has attracted considerable public interest.

This fuel was discussed in the R.38 Prize Essay, which the author submitted in 1927. It has since been used in L.Z.127 on her trans-Atlantic flight.

It is a mixture of hydrocarbon gases derived by cracking oil. It is probably very similar to the gas used for the illumination of railway trains and which is said to have contributed so much to the fire in the recent railway accident at Charfield. It is stored at atmospheric pressure in gasbags under the hydrogen bags.

Very successful tests have been made at Cambridge with fuels of this general type and of densities both above and below that of air. Modifications have now been introduced which, in the author's opinion, constitute very important advantages for the practical use of this fuel in an airship.

Gaseous fuel undoubtedly gives greater power per unit displacement than is possible with petrol.

As compared with the more efficient compression-ignition engine using heavy oil, this advantage almost, if not wholly, disappears, but gas still has the advantage that it can be burnt in normal aero engines as distinct from the heavier type at present necessary with heavy oil.

On the vitally important point of safety it appears fairly certain that the fire risk connected with this gas is of the same order as that with petrol. The risk is far greater than that with heavy oil or with hydrogen. This is the conclusion reached in two quite independent investigations, while no evidence to the contrary has so far reached the author, who is most anxious to consider such evidence as can be obtained.

The only serious disadvantage to the heavy oil system is the weight of the engine. That is likely to be greatly reduced by refinement of the present design and by the development of designs by other makers who realise the importance of using this safe and cheap fuel, not only in airships, but in all future commercial aircraft.

Conclusion

It is perhaps premature to describe the machinery installation of this airship before it has undergone the vital test of flight.

[illegible]e Council, however, pressed for the lecture to be given at this time. [illegible] agreed to, partly because criticism is welcome while there is time to [illegible]ification and because it is hoped that at the end of the [illegible] tests are in progress, further papers connected with the [illegible] and handling.

[illegible] probably [illegible] that the objectives have been [illegible] but there may be criticisms that the engine [illegible] at the time of the [illegible] separately.

[illegible] is due to the [illegible] and with torsional resonance. Had [illegible] not occurred there would [illegible] for testing a complete unit [illegible] gantry under conditions [illegible] to those of flight. This would have resulted in thorough [illegible] engine units—a great advance on the conditions of the first trials of earlier airships.

The delay has been unfortunate, but has not, it is submitted, justified turning aside from what must be accepted as the safest system and eventually, perhaps, the most economical also.

The machinery installation and the work leading up to it have been devised and carried out by the Staff of the Royal Airship Works, who are content that acknowledgment should be made to them as a whole, and this the author does with great appreciation.

At the conclusion of the paper the author carried out experiments to demonstrate how small was the risk of fire when using the fuel oil.

He first played a Bunsen flame on the surface of a quantity of fuel oil.

Some petrol was then poured into a metal tray and ignited. It was, however, extinguished by fuel oil poured into the tray.

The author submitted that it was worth doing anything within reason to hasten the time when fuel oil of this nature would replace in all aircraft the petrol now used.

Appendix

Draft Specification

1. *Description.*—The oil shall be free from solid impurities and water.
2. Viscosity.—The viscosity of the oil shall not exceed 0.26 poises at plus 0°F. (−17.8°C.). This is equivalent to 120 seconds Redwood with a specified gravity of 0.870 at 15.5°C. (water at 20°C. = .01 poise).
3. *Flash Point.*—The "closed" flash shall be not less than 210°F. (99°C.) when determined in the Pensky Martin apparatus.
4. *Sulphur Content.*—The sulphur content shall not exceed 0.5 per cent.
5. *Free Mineral Acid.*—The aqueous extract shall be neutral to methyl orange.
6. *Ash.*—The ash content shall not exceed 0.025 per cent. by weight.
7. *Asphaltic Matter.*—The amount of asphaltic matter shall not exceed 1 per cent. by weight when tested by method described in appendix below.
8. *Cold Test.*—The oil shall not cease to flow when exposed for one hour at −10°F. (−23.3°C.) when tested by the method described in P.4. (Prov. B.E.S.A. Specn.)
9. *Hydrogen Content.*—As water is to be recovered by condensation of the exhaust gas preference will be given to oil having a high hydrogen content.

Method for Determination of Asphaltic Matter

The oil shall be dissolved in 40 times its volume of petroleum spirit (B.P.40°C. to 60°C.) and the solution allowed to stand for 24 hours. It shall then be filtered and the asphaltic matter on the filter washed with petroleum

spirit until free from oil. The asphaltic matter shall then be dissolved in benzol (Spec. 2D.10.) and the benzene solution evaporated to dryness in a weighted dish. The residue left on evaporation shall be regarded as the amount of asphaltic matter present in the oil.

Discussion

Mr. A. E. L. Chorlton: He was glad that the word "Diesel" was not mentioned in the paper. The British have a national habit of giving credit to foreigners usually, and denying it to Britishers. The engines of the R.101 constitute a normal development of the original Stuart engine, which was designed earlier than the Diesel engine. A difficulty with the airship engine is that it has to be a variable-speed engine, and has to run at any speed within its range for lengthy periods if necessary, and this is not the case with other aircraft engines. As all engines must have a crankshaft there must be vibrations, and it is necessary to provide some means of damping these vibrations. He had been concerned with engines of this type, which have run satisfactorily in railway service for eight years. The airship engine has to drive a propeller, which introduces still further difficulties, and he admired the way in which the problem has been tackled mathematically. Major Carter is to be congratulated particularly on having determined almost to a revolution the exact critical speed. A larger crankshaft is one solution, and about three years ago, in the United States, a crankshaft was used for a straight-eight engine having a diameter three-quarters that of the cylinder, and experience has since proved this to be about right.

The essential feature of the engine is the pump with its rapid action, for there must be rapid action to secure a wide speed variation of the engine, and easy starting. This engine is started easily, even at low speed, as is indicated by the small power required to turn it over. He was much impressed by the evaporative cooling results, and if fuel oil engines were used for motor cars the same methods of cooling would have to be adopted. With regard to the exhaust boiler, he would point out that the greater the economy in the engine, the less the need for the boiler. Unless 40 per cent. of the total heat used is ejected from the exhaust the boiler might not be worth while. In any case, the boiler has to be of special design, and that described by the author has given very good results. Good results were also obtained in other spheres with the Clarkson boiler.

Captain F. Boothby: Very necessary experiments are being carried out with a view to evolving a heavy oil engine suitable for use in aircraft, and when such engines have been evolved, weighing 4lb. per brake horse-power which will withstand full-power trials for twenty-four hours, and when there is a propeller which will withstand the conditions, he would be strongly in favour of installing them in all airships, but to fit these heavy oil engines to an airship at the present stage of development and to send that airship into the air is to incur a grave risk. The engines of the R.101 were designed to give 700 b.h.p. maximum, presumably with a weight of 8lb. per brake horse-power, but in the last test the power developed was not more than 75 per cent. of that, so that the engine weight is increased to 12lb. per brake horse-power. Again, presuming that the engine on the centre line is the one to be used normally for bringing the ship up to the mooring mast and to get the slipstream on the rudder, and that engine were to fail, the airship would be out of control when trying to moor. He was not suggesting that the experiments should not have been made, but that they should be carried out before the engines were fitted to the airship, not afterwards. It would be better to use well known engines of standard type, because it is important to the whole airship movement that this particular ship should be a success, and it is a great

pity to do anything which would be likely to jeopardise its success. The Atlantic flight of the Graf Zeppelin emphasised the need for swivelling propellers. He believed the Shenandoah was lost through lack of them, also the Italia and N.S.3, and that the Graf Zeppelin would be safer if so fitted.

Mr. CHORLTON: Engines exactly similar to those of the R.101 have been running for three and a half years in railway service, and each engine has run nearly 200,000 miles. It is going rather far to say that they have not been tried out, because one knows of no other engine which has been tested so thoroughly.

Colonel V. C. RICHMOND: We are told that because one cannot claim to have reached the high standard aimed at one ought not to try, but the people who have to fly these ships through the tropics would a thousand times rather fly them with the heavy oil engines, in spite of the difficulties to be contended with, than with petrol engines. The views of those who have to operate the ships must be considered. Dealing with the author's remark that the external shape of the car is fair enough, and its size small enough, to satisfy all but the most exacting aerodynamic enthusiasts, he would say that the diameter of the car is slightly less than half the diameter of the airscrew, but that does not satisfy the aerodynamic enthusiast. He felt sure the author does not mean to suggest that the efficiency of the combination could not be improved by increasing the ratio of airscrew diameter to car diameter, but so much has to be put into the car that one can do no better. With regard to water recovery, he was not prepared to go quite so far as the author has done in saying that "What appear to be satisfactory means have been found for dealing with the dirt and acid in the exhaust." Certainly a new system is being tested, but there is much to be done before it can be regarded as satisfactory. Referring to gaseous fuel, he would like to emphasise the author's remarks with regard to safety. Gaseous fuel, to be economical and efficient, must have a density of something between 50 and 100 per cent. of the density of air; he maintained that it is not a good thing to have the bottom half of the hull of the ship filled with this gas, and one must be careful not to adopt an arrangement which is far less safe than when petrol is used. With regard to the economy of the arrangement, one had not yet heard enough about the weight of the installation. On the face of it, it appears to be very nice to be able to say that there are no petrol tanks and that the gas is stored in bags, but the extra amount of fabric required to make double or sub-divided bags is a very serious item.

Mr. F. HANDLEY PAGE: With a view to making a comparison of the weight of the engine installation of the R.101 and the weight of the engine installation of an aeroplane, can the author give the weight of one of the actual cars? He would also like to ask what are the possibilities of producing heavy oil engines at a weight of, perhaps, 2 or 3lb. per brake horse-power instead of 8lb.

Engineer Captain BEEMAN: Referring to the torsional vibration problem, when the engine was tried with the airscrew, did the air entrained by the propeller alter the moment of inertia to a sufficient extent to warrant this influence being taken into account when estimating the frequency of torsional vibration of the engine propeller system?

Mr. H. B. TAYLOR: The method of starting the main engines by installing another engine means a good deal of extra weight, and the use of petrol, though the quantity carried may be small; this quantity is, however, considerably greater than that required only for the purpose of starting the main engines, as the petrol engine is to be used to drive dynamos and air compressors. The petrol would be carried in the engine car, where the greatest danger is likely to arise. An alternative method of starting is to use an inertia starter, which is now being developed, particularly in the United States, combined with a hand priming device, so that the fuel system would be thoroughly primed ready to kick off

before the inertia starter is applied. That arrangement holds very great promise as a means of starting compression ingnition engines, one of which—not a petrol engine—carried on the body of the ship could be used for the auxiliary services, giving a considerable saving in weight. With reference to the steam or water separator, he would like to ask whether any considerable quantities of water are carried over with the steam into the main condensing ducts; that would involve the possible danger of denuding the engine of its normal water supply, because the ducting for the steam would be of ample dimensions.

Mr. R. M'Kinnon Wood: He would have expected to have found between the engine and airscrew a reduction gear of about 2 : 1. The author has stressed the importance of airscrew efficiency in an airship, and stated that he was getting a very satisfactory airscrew efficiency. From the figures given, however, he thought the author was getting an efficiency of well under 70 per cent., when he might have obtained one of well over 80 per cent. with a reduction gear.

(*Communicated*): The estimate of the efficiency of the airscrews was based upon the figures in the paper, viz., 75 m.p.h. and 1,000 r.p.m., which give an advance per revolution of only 0.41 diameter. Gearing would be used primarily to raise this to, say, 0.8, and so to reduce the loss due to the relatively high ratio of tip speed to forward speed. Secondly, it would reduce the further loss which is anticipated owing to the absolute value of the tip speed being rather high; and thirdly, it could be used to raise the efficiency by increasing the mass of air dealt with; but one would not have expected the use of airscrews of much greater diameter if gearing had been incorporated.

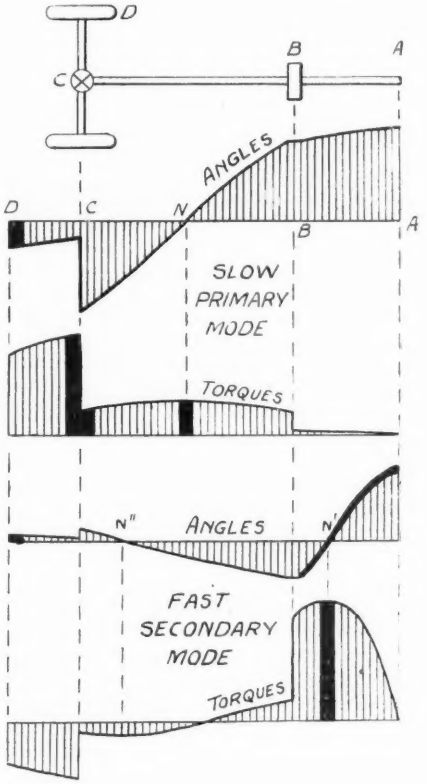
Professor B. P. Haigh: Speaking as one who has investigated torsional oscillations in other cases, he believed that the trouble experienced in this connection in R.101 will certainly be overcome by the means proposed. Every engine shaft, together with the shafts connected to it, constitutes an elastic system with several natural frequencies corresponding to different "modes" of vibration. These frequencies can be calculated with fair accuracy, or can be found by trial.

Two modes of torsional oscillation usually require to be considered, the primary—in which the two ends of the system oscillate in opposite directions—and the secondary—in which the two ends turn in the same direction, opposite to the direction of the mid-part of the shaft. In marine propulsion, the primary mode is sometimes unimportant, as it is heavily damped by the propeller in water, but it is necessary to keep below the higher critical speed corresponding to the secondary mode.

The two critical speeds, and the phenomena in general, are perhaps more familiar in motor cars. The low primary frequency is that observed when a car slows down in traffic or on a hill until that "surging" or "labouring," often experienced by drivers who are too slow in changing down, is felt, while the higher secondary critical is that experienced at much higher speeds, when the engine shaft oscillates severely, without unduly disturbing the road wheels or the body of the car.

In the engines of R.101, it appears that the primary mode of vibration has been the source of the trouble experienced. It is stated in the paper that a new engine shaft had been designed so very much stiffer than the previous one that "the" major critical speed would be well outside (he presumed above) the running speed; and, a little later, it is stated that it had been decided to fit, between the crankshaft and the airscrew, a spring coupling of stiffness so calculated as to bring "the" major critical speed far below the running speed. This sounds rather as if the author were administering a sedative with one hand, and at the same time a stimulant with the other; but the real meaning of the change is very different. By introducing the elastic coupling, the author would reduce the primary frequency—that had given the trouble—well below the running

range, and by stiffening the engine shaft, he would keep the secondary critical speed well above the running range, and also reduce the danger of " minor " secondard criticals which might be encountered at somewhat higher speeds, and had been found in some cases to be a real source of danger. The policy adopted by the author appears therefore to be an example of admirable engineering judgment.



The figure serves to contrast the main features of the two modes of torsional oscillation in a typical motor car shaft on direct drive. The first and third graphs represent the angles of oscillation at different sections along the shaft, while the second and fourth represent the variations of torque above and below the mean value.

In the low frequency primary mode, represented by the first and second graphs, there is only a single " node " N—usually found in the propeller shaft or in the rear axle. All parts forward of this node vibrate clockwise when parts aft of it turn counter-clockwise, and vice-versa. In this primary mode of vibration, the range of torque is only slight in the engine shaft, and much more severe in the propeller shaft and rear axle—near to the node. For this reason, drivers who do not change down until the engine begins to " labour " are more liable to experience troubles in the rear axle and differential, although they may not necessarily suffer any engine trouble. It is this critical that limits in practice

the slowest speed at which cars can run smoothly on direct drive. The critical frequency can be reduced by using a thinner propeller shaft or a heavier flywheel, or even by loading the car. For one and the same shaft and flywheel, the critical revolutions are reduced by using a six-cylinder instead of a four-cylinder engine.

In the high frequency secondary mode of vibration, now fairly well known in straight-six or straight-eight engines, there is little vibration except in the engine shaft AB. The flywheel B effectively limits the vibration in all parts to the rear, and the driver of the car seldom notices the small amplitude of the road wheels D, as this small amplitude is taken up by the tyres. The critical frequency for this type of vibration can be increased by using a shorter engine shaft, or one of larger diameter. As the secondary frequency is high in short four-cylinder engines—and the engine impulses less frequent—the conditions for resonance are seldom reached in ordinary driving with four-cylinder engines. But in six-cylinder engines and straight-eight engines, the working speed often runs through the critical, and dampers have to be fitted to mitigate the ill effects. In the secondary mode of vibration, the torque variation is most severe in the after part of the engine—near the node N—and it is hereabouts that fractures occur. Those who have experience in interpreting such graphs will recognise that the steep run of the amplitude graph in the engine shaft AB in the third diagram is a warning that " minor " as well as " major " critical speeds have to be considered in this case—particularly in six-cylinder engines. In most cars there is only one primary critical speed on each gear, but several secondary criticals.

For practical purposes, in cars, there is no great error in regarding the primary mode of oscillation as confined to the flywheel B and the shaft BCD behind it, and the secondary oscillation as confined to the flywheel B and the engine shaft BA in front. This simplified picture of the action helps us to gain a first impression of the relation between the two actions, and to see, also, that the use of a heavier flywheel reduces both the critical frequencies—making the car easier to drive on top in traffic, but liable to the secondary action at a lower running speed.

Mr. A. F. Evans: Is it not a fact that some cylinder trouble might be prevented incidentally by the method employed for starting small Diesel engines such as are used for vehicle work. The engine is cranked a few times with the valves propped open to allow of easy cranking, but at the same time the fuel is being sprayed into the cylinder, the result being that before ignition takes place the cylinders have been lubricated with petroleum having a flash-point of about 200°F., which may be considered quite a reasonable " Upper Lubrication."

Another feature is that with the Diesel the crankcase oil is free from dilution by distillates from the petrol.

Reply to Discussion

Wing Commander Cave-Browne-Cave, in replying on the discussion, said: An engine with eight cylinders in line must have a comparatively long shaft, and if the strength of the shaft were made no greater than necessary to provide for the normal torque fluctuation, it would have a low torsional period likely to come within the running range. Of the final weight of the Tornado engine, perhaps 20 per cent. is due to the various measures introduced solely to overcome torsional resonance troubles. In a well-known twelve-cylinder Vee engine of about the same power, there appears to have been no increase of weight for a similar reason.

The difficulty of torsional resonance is not really serious, once it is realised. I do not think the work of Major Carter had been fully appreciated, but as the result of that work we can now predict with extraordinary accuracy, from the drawings of a crankshaft, what its dangerous speed will be. The design can

then be dealt with by perfectly well-recognised methods, so as to bring the dangerous speed where it does not matter. In my view the problem of torsional resonance has been placed on a thoroughly sound basis.

I agree with Captain Boothby, that longer engine trials on the ground would have been desirable, but as that had not proved possible, it is better, particularly if the long view is taken, to use the compression ignition engines in their present stage than to accept the delay of building new units for petrol engines and surrender the whole of the safety connected with the use of heavy oil. Many engine failures, at any rate one at a time, can be accepted, but one bad petrol fire would be conclusive.

The engine weight quoted as about 8lb. per brake horse-power is based on the continuous full power which the engines actually develop.

The starboard forward car would contain the "astern" engine, and would exert very little moment to swing the airship. The centre line car must at low speed be available to give an air stream over the rudder.

The mechanical difficulties and the weight of swivelling airscrews are not, in my opinion, justified by the very occasional benefit which can be derived from them. If LZ.127 had had swivelling airscrews on the occasion to which Captain Boothby referred, it would probably have been safer to continue to use them ahead and thereby maintain the dynamic lift than to use them vertically, and risk losing the dynamic lift and the controllability of the airship.

I cannot accept Mr. Chorlton's protest against Captain Boothby's suggestion that the engines are comparatively untried. The engines, which Mr. Chorlton has run so satisfactorily, differ from the airship engines so much as to render the comparison of little value.

In reply to Mr. Handley Page, the weight of the complete unit is scarcely relevant, because it includes apparatus for driving auxiliaries. The weight of the car structure and fairing is about 650lb., or, say, 13 per cent. of the main engine and airscrew.

The engines are controlled by an engineer on watch in each unit, who carries out orders transmitted by telegraph.

As to the possibilities of a lighter engine to burn this fuel oil, I expect that details of an engine weighing less than 3lb. per brake horse-power will be published shortly.

In reply to Engineer Captain Beeman, by comparison with the other rotating masses the moment of inertia of the airscrew is so large that any virtual increase of its mass would have no practical effect. The elasticity of the blades and the movement of the air possibly give rise to some damping effect.

I agree with Mr. H. B. Taylor that centralised auxiliary engines and electrically-spun inertia starters for the main engines are a very attractive combination. The present petrol engines are purely a temporary expedient, and will be replaced by the compression ignition engines at a very early stage.

The quantity of water carried over as liquid to the condensers is very small. The volume of steam in the engine varies with the heat flow, and therefore with the power. It is therefore inevitable that some water must be discharged when the brake horse-power is increased. This consideration necessitates a reserve water tank rather than a separator.

In connection with Mr. M'Kinnon Wood's suggestion that the airscrew efficiency could be increased by gearing withou greatly increasing the airscrew diameter, previous proposals to use gearing, although they promised improved efficiency, included larger airscrews, which involved greater weight and longer engine car suspensions, both of which are objectionable.

Professor Haigh's remarks summarise exactly the torsional resonance situation of the main engines.

I have stated that the fuel oil is not expensive. As compared with aviation petrol at £25 per ton, it costs about £5 per ton. Assuming that the petrol engine burns to 0.55lb. per brake horse-power per hour, as compared with the oil engine burning 0.385lb. per brake horse-power per hour, and that the densities are 0.76 and 0.87 respectively, the following interesting comparisons can be made for a given number of brake horse-power hours:—

	Petrol.	Fuel Oil.
Cost of fuel is in ratio	100	14
Volume of fuel is in ratio	100	67

showing not only a very attractive reduction in fuel cost, but a reduction in the size of fuel tanks which the aircraft constructor would appreciate.

Colonel L. F. R. Fell (*communicated*): The statement that gas fuel is equally dangerous from the point of view of fire as is petrol is difficult to accept. With petrol, the great danger is that the complicated pipe system necessary to admit of the fuel being moved rapidly from one part of the ship to another for trimming, means almost for certain small unavoidable leaks and, in consequence, the presence of petrol vapour in large quantities in the keel, immediately below the hydrogen containers. The oil gas is slightly lighter than air, and it is difficult to appreciate why a gas bag filled with oil gas, which will burn over a comparatively narrow range, and which displaces a gas bag filled with hydrogen, which will burn over a very wide range of mixture strength, can possibly increase the danger from fire to the airship.

Mr. D. D. Borland (*communicated*): The author describes an interesting scheme for cooling the air in the engine by drawing the whole of the air for combustion through the crankcase, but says that the idea was abandoned owing to the possibility of an explosion being caused by a flame from an open inlet valve, though in other respects the plan was quite satisfactory. No doubt the author has given consideration to an obvious remedy for this difficulty, namely, the use of wire gauze on the Davy lamp principle, but one would be interested to learn what were the objections he found.

A similar problem occurs on the ordinary two-stroke engine using crankcase compression, except that instead of there being only a possibility of an explosion in the crankcase it is almost a certainty. On the Trojan two-stroke engine, it has been found that a nest of four gauzes, placed adjacent to each other in the induction passage, prevents base-chamber firing absolutely, while they run for long periods without clogging or sooting up.

Colonel A. E. Davidson (*communicated*): Despite some criticism which has been made as to the use of compression ignition engines he was very glad, from the army point of view, that their use should have been proceeded with, as the army also are extremely interested in obtaining engines of this type which will free them from the risk of fire.

He would like to join Mr. Chorlton in his comments regarding the nomenclature of these engines. It does seem as though the name is an exceedingly good one because it brings out their principal feature, namely, that ignition is brought about by the heat of compression, and this was a feature exploited at an early date in British made engines of the Hornsby-Akroyd type.

On the question of accessibility of engines and the size of their gondola, lorry makers are now designing engines for use in forward-control chassis where all the auxiliaries are on one side, and no access is permissible to the other side of the engine. He suggested that in future engines and gondolas it might be worth investigating this feature with a view to diminishing the width of the gondola by doing away with the "cat walk" on one side.

Speaking as a mere landsman, the whole installation is a tremendous lesson in relativity. The complete engine gondola seems to be such a small unit to control such an enormous vessel. The author, too, by what he does not say leaves much to the imagination regarding the other features of mechanical engineering, by which alone the design and construction of such a vessel is possible.

To one used to the difficulties met with in the very short fuel, lubricating oil and water services on motor vehicles, the extraordinary lengths of piping required in an airship for these services fill the landsman with alarm.

The suggested method of cooling the lubricating oil, namely, by taking the air of combustion through the crankcase, seems to be rather a dangerous practice owing to the possible contamination of the oil by impurities in the air. In tropical lands the dust is caried up to a great height, and it might be difficult to filter the air properly. He thought that it would be sounder to take incoming air through nests of tubes passing through a lubricating oil tank. No risk of explosion could thus arise.

Mr. SPANNER (*communicated*): The plea is advanced that the adoption of heavy oil as fuel is of most extraordinary importance, from the safety point of view.

One was not greatly impressed by the demonstration given by Wing Commander Cave-Browne-Cave of the non-inflammability of the new heavy oil. The two experiments he performed, one in directing a flame against the surface of a vessel containing the new oil, and the other in using a volume of new oil to put out a tray of flaming petrol, are both of them of the nature of conjuring tricks.

Everyone knows that heavy oil will burn and burn fiercely and freely if it has a wick. It is also the case that spectacular experiments can be performed with even light oils might give the unscientific onlooker the impression that he was witnessing a phenomenon.

The whole question of the value of the safety advances made in the adoption of heavy oil for the engines of R.101 is concentrated in the one fact that heavy oil does not evaporate at sufficiently low temperature to give off an explosive gas, under the normal conditions R.101 is likely to encounter. If this oil did flash at a low temperature then there would be danger that a spark might cause an explosion which would result in a fire. An explosive mixture of evaporated gas quickly forms what has judicially been termed a "seed of fire." No argument is required to establish the fact that if a fire is once started in an engine car of R.101, or in the vicinity of storage tanks of the heavy oil being used in the ship, this oil will undoubted burn, and burn very fiercely. Many such fires have had to be dealt with in ships. Recently a Court of Inquiry has delivered judgment on the extremely serious fire which took place in the ss. Carmarthenshire, when burning heavy oil fuel defied for a long time all efforts to put it out.

The question to be answered by the designers of R.101 is, "Have you entirely eliminated the risk of gaseous explosion in the engine cars of R.101 by the adoption of heavy oil fuel?" The answer is "No"—because in the same engine cars as accommodate the heavy oil engines there are small petrol engines, and a small petrol tank storage for driving those auxiliary engines. The gas from this petrol tank and engine in so confined a space, may easily provide the much dreaded "seed of fire," and a fire, once started, would feed ravenously upon the heavy oil being used for the main engines.

The Main Engines.—Such troubles as have been experienced with these are neither of a novel type nor troubles presenting insuperable difficulties. One has every belief that heavy oil engines of the Tornado, or other type, will eventually be designed and built to run satisfactorily at a low consumption and at a low weight per b.h.p. One cannot agree, however, that these engines are ever likely

to be as light as petrol aero engines, for reasons fundamentally concerned with the principles of operation of this type.

It is extraordinarily interesting to note that the need for all elaborate experimental work on variable pitch airscrews has arisen *because the mooring of rigid airships to masts has at last been recognised as presenting serious difficulty.* No other rigid airship has ever had variable pitch airscrews. Why R.101? Is it because the Air Ministry are nervous about handling her to a mooring mast? At any rate the position is that although so much work has been done and money spent on elaborate experiments, the variable pitch gear invented by Air Ministry experts has not yet been really satisfactorily tested. The hollow propellers have failed, solid ones cannot be fitted yet for reasons concerned with weight and strength, and R.101 is to be sent into the air with five engines—*only four of them, however, to be used for going ahead.* One of the engine cars is so much useless weight, so far as driving the ship from point to point is concerned, but it is necessary because its engine is essential to drive an "astern" airscrew when the ship is coming to a mast.

The author says the thrust wire bearing necessary to enable the power car to sustain a heavy load, "even when the airship is pitched steeply down and the engines are developing full power" has "proved entirely satisfactory under large over loads and under prolonged test at normal load."

It would be interesting to know how those tests were applied, since one understands the engines have never yet been run in the car to develop full power. Incidentally, it is interesting to note that it is now accepted that airships have to fly "pitched steeply down" and with their engines developing full power.

Evaporative Engine Cooling.—This is admitted to be in a state in which dependence cannot be placed upon "fabric duct" cooling. One anticipates many difficulties in using "fabric ducts." However, money has been spent on preliminary "fabric duct" experiments, although in R.101 radiators are to be fitted.

The use of steam-heated air for warming the passengers' quarters is likely to prove extremely uncomfortable for the passengers, if ship experience is anything to go by. Why does Commander Cave say that this ventilation "radiator will not be liable to freeze?"

Two different types of exhaust boiler have been invented and tried, *neither of which is now to be fitted.* One of these designs was admittedly a "wash-out." One's own experience of waste heat boiler work convinces one that the other, of which drawings were shown, would have proved entirely useless in practice, although Wing Commander Cave-Browne-Cave reckons it a success. Commander Cave is obviously not at all worried by financial considerations, and proved this by calmly talking of "cutting the boiler shell to pieces in order to inspect it," and then welding new parts in. The decision that stainless steel was to be used in subsequent boilers to avoid the serious corrosion experienced in this "satisfactory"(?) design, was apparently taken quite light-heartedly. Cost means nothing at all to Air Ministry experts. It certainly is time the taxpayer woke up.

Extravagance apart, this satisfactory(?) design would fail after a very short time in actual use, for reasons which any one of two or three reputable waste heat boiler firms would no doubt be pleased to advise the Air Ministry.

Sir Samuel Hoare told the Dominion representatives in 1926 that it would take 60 hours to get to Egypt. Wing Commander Cave-Browne-Cave has stated that the R.101 will be equipped with four ahead engines developing a continuous full power of not more than 2,340 b.h.p., although this is only about two-thirds the full power originally estimated for the ship. Certainly one would think that

with an ahead power of only this amount, the speed of the airship would naturally be slower, and there would be no possible chance of the vessel reaching Egypt in less than 60 hours. Yet Commander Cave-Browne-Cave states that the whole of the arrangements made with regard to fuel supply and so on are on the basis of only a 50 hours flight.

Discussing the fuel storage system, Commander Cave even cuts this 50 hours to 40 hours, and suggests that R.101 will attain a speed of 76 miles an hour against an average head wind of 15 miles an hour and get to Egypt in 40 hours. One would be glad if Commander Cave would explain exactly how far R.101 is expected to get in 50 hours, and the ahead h.p. and air speed she must develop to cover this distance.

It appears astonishing how little space is available in the engine car of R.101 for the engineer. These engine cars appear nothing more nor less than death traps. There is no more than room for one man to move about. To describe the engine as accessible is sadly to strain that word.

In each engine car there is to be, one undertsands, a heavy oil engine, a small petrol engine, petrol tank and other small auxiliary engines. The shape and construction of the car and its immediate proximity to the airscrew, seem to ensure the engineer an extremely uncomfortable watch. Further, one doubts the possibility of ventilating the car sufficiently well to obviate any danger of the engineer actually being poisoned by fumes from the engines. In marine work a certain amount of trouble has been experienced owing to poisoning of engineers in quite large engine-rooms, in which one would hardly anticipate any such trouble. The lot of the engineers of R.101 will certainly not be an enviable one. Should a man collapse in an engine car it is going to be a difficult job first of all to get knowledge of his collapse, and secondly to save him from asphyxiation.

Since the car has not been tested with the engine developing more than 75 per cent. of its full power, it is impossible to express any satisfaction that the arrangements made will prove adequate.

The compressed air system, for moving fuel and water, has decided limitations. The process of moving fuel by compressed air through small 2in. pipes over considerable distances will take quite an appreciable time. There is no possible chance that any such system will help to minimise the movement of the airship when she is caught in a storm, while of course it will not have the slightest effect in simplifying the work of the pilot, when he has necessarily to fly his ship pitched in order to obtain dynamic load or lift.

The arrangements for the emergency discharge of fuel are interesting. Apparently considerable attention has been given this problem, although one can hardly congratulate aeronautical experts on overlooking the necessity of providing a sufficiently large vent in their first experimental tank. The precaution was so elementary.

One cannot share Commander Cave's optimism that the stream of fuel will fall completely clear of the airship envelope, as one is inclined to believe that the downward movement of the airship itself, at such times as called for the use of emergency ballast, will be so rapid as to result in the airship actually passing through this thunderstorm of oil fuel drops to which Commander Cave refers.

As fuel oil stains spread rapidly, are extremely corrosive in effect and difficult to remove, one may expect the envelope of R.101 to suffer severely the first time oil fuel has to be dropped in real emergency.

There are, of course, many special pipe joints on the market, and the one referred to by Wing Commander Cave-Browne-Cave presents no very exceptional features. One notes it has been tested under 24 hours of rapid vibration, but as

this is hardly the type of experience most likely severely to test the oil-tightness of the joint, the results are not convincing.

As a matter of fact this 1,500ft. of piping system will be called upon to "give and take" with the movements of the airship skeleton, and a proper test of the oil-tightness of these joints should include straining of this character.

Experience with ship work, in which liability to pipe strain is less than it will be in R.101, leads one to anticipate that trouble will certainly be experienced with leaky joints after the first half-a-dozen long-distance flights.

It is something of a paradox that while the Air Ministry should be making so great a feature of the safety of the heavy oil engine, they are satisfied to allow the whole safety of the passengers and crew to depend upon so inflammable a gas as hydrogen. A somewhat curious position is reached in which the Americans are satisfied to use petrol for their engines, but insist upon having helium as the lifting gas, while the Air Ministry are satisfied to have hydrogen as the lifting gas, but insist upon having heavy oil engines in the engine cars.

The term "safety," of course, is relative in any case and there are many people who consider the word safety used in reference to rigid airships to be quite out of place.

In replying to the written communications, Commander CAVE-BROWNE-CAVE wrote: On the question of gas fuel raised by Colonel Fell, I consider that the likelihood of leakage of fuel gas from its storage system and mains is about equal to the likelihood of leakage of petrol. The limits of explosive range are about the same.

It must be remembered that over the lower surface of a hydrogen gas-bag the internal pressure is usually less than the external, so that through any hole gas would not tend to pass out and reach a source of fire outside, but air would tend to pass inside, where there would, presumably, be no source of ignition. The danger from any small hydrogen leak is small because, although the limits of explosive range are wide, the speed of dissipation is very rapid.

In so far as reference to the Charfield railway disaster is relevant at all, I understand that the seriousness of the fire was due to the release of large quantities of inflammable gas rather than to the number of exposed sources of ignition.

Colonel Fell appears to have overlooked the experimental work which has been done to arrive at the fuel oil specification for R101. There appears to be little difference between one oil and another so far as use in the cylinder goes. The discriminating factor is the compromise between high flash-point, as controlling safety from fire, and low setting point, as controlling flow at low temperature. This has given rise to very careful consideration and a good deal of practical experiment.

Mr. Borland suggests that gauze should be used to prevent the passage of flame through the oil cooler. A gauze diaphragm has been used, but it was of large area to avoid restricting the flow of air, and might therefore have involved considerable weight if it had to be strong enough to resist damage by explosion.

Colonel Davidson's suggestion that all parts which might require attention should be confined to one side of the engine would give less advantage than he anticipates, because, unless the car is symmetrical about the airscrew axis, the propeller efficiency is considerably reduced.

Dust in the air over the desert is certainly a potential disadvantage to the crankcase oil-cooling system, but, perhaps, not a very serious one. The oil radiators used afford in a given space a greater cooling surface than could

easily be achieved in tubes through an oil tank. That surface is, however, small by comparison with the 100 sq. ft. available, gratis, inside the crankcase.

Mr. Spanner's contribution, especially in its unabbreviated form, contained points of which some were scarcely pertinent and others could be answered by reference to the text.

It illustrates the danger of misunderstanding, which is incurred by describing anything before it has been wholly proved successful.

Mr. Spanner's remarks about the fuel oil are based on his assumption "if the oil did flash at a low temperature." It does, however, not do so. The experiment shows that the fuel oil cannot at atmospheric temperature be ignited by the application of a flame, and is, therefore, much safer than petrol. The same thing could have been done with paraffin lamp oil at atmospheric temperature. If, however, the fuel oil had been in contact with the surface of a water-cooled engine, it would not have been ignited by a flame, the paraffin lamp oil would, at that temperature, have been giving off gas so rapidly that it could have been easily ignited and would have burnt freely.

The author does not agree with Mr. Spanner that under the conditions existing in an engine car fuel oil, when once ignited, will burn fiercely. His comparison with boiler-room oil fires is not wise, because there the oil is pre-heated in special heaters to well above its flash point, and the boiler fronts have large surfaces at temperatures far above the flash point of the oil. These may cause any escaping oil to give off vapour rapidly, and therefore to burn fiercely. There is, however, in the airship engine car nothing corresponding to these hot surfaces or to the wick which Mr. Spanner proposes. The oil is not pre-heated.

The petrol auxiliary engines are purely a temporary expedient, but do not, as they are installed, constitute a serious risk of causing a fire which could extend beyond the particular engine car or persist for more than a very short time.

The primary reason for the variable pitch airscrew is to provide the astern thrust, which has proved necessary in previous rigid airships, whether landing to a ground party or to a tower.

The thrust wire bearing was tested by the application of an external load equivalent to the tension in the wire under extreme conditions. The engine could not be run at more than 75 per cent. of full speed, but as there was no appreciable rise of temperature, it is probable that the bearing will be satisfactory in flight. Each bearing will, however, be tested at full load and speed, as each power car does its acceptance test.

The passenger heating radiator is unlikely to freeze, because under cold conditions it will be so far drawn within the hull for heating purposes.

The reason for developing a special exhaust boiler is that the weight and space available are less than would accommodate a boiler of commercial type. The increased cost of material, if stainless steel had been used, would be £17 10s. 0d. per boiler. The cost of the 16 sq. ft. section of plate to replace that cut out for examination would be 2/6d., if stainless steel were used.

The time taken on the passage to Egypt depends upon the route followed and on the wind. Taking the longest of the three routes which have been examined, and assuming a contrary wind of 15 miles/hour over the whole of this route, the time taken with five engines would be 46 hours and the fuel burnt 24 tons. If, however, four engines only are used, the time taken will be 52 hours and the fuel burnt 22 tons.

Practical experience during the tests of the engine car has shown that there is no lack of ventilation.

Mr. Spanner's suggestion that the airship will be driven down through the ballast she has discharged, appears ill founded. If the airship is being driven down, the air which is driving her down must presumably be moving downward relative to her and will cause the discharged ballast to fall away more quickly than it does in still air.

The vibration test of the pipe joints exposed them to internal pressure, longitudinal tension and bending. The meaning of Mr. Spanner's "loose" term, "give and take," is not clear, but the effect is perhaps covered by the test.

Mr. Spanner draws attention to the fact that America uses helium and petrol engines while the Air Ministry have expended much effort to develop heavy oil engines, but are satisfied with hydrogen.

The author understands on excellent authority that America will adopt a heavy oil engine for airships as soon as a satisfactory engine of that type is available to them.

The only practicable supplies of helium are at present under American control.

Mr. Spanner refers to items, already available from commercial sources, which would have avoided the cost of experimental work. If he will examine each of these in comparison with the corresponding item described in the lecture and will send in particulars of those which he really considers preferable for airship service, their suitability shall be carefully compared.

PROCEEDINGS

SEVENTH MEETING, FIRST HALF, 64TH SESSION

In the Chair: THE PRESIDENT, COLONEL THE MASTER OF SEMPILL

SOME ASPECTS OF THE PRODUCTION PROBLEM IN AIRCRAFT

BY

F. SIGRIST, M.B.E., A.F.R.AE.S.

The above meeting of the Royal Aeronautical Society was held in the rooms of the Royal Society of Arts, John Street, Adelphi, W.C.2., on Thursday, November 29th, 1928.

The PRESIDENT: The technical aspects of the production of aircraft were of considerable importance because, from whatever point of view one regarded aircraft, economical and rapid production were essential. Mr. Sigrist is a Director of the Hawker Engineering Co. He was associated with Mr. Sopwith as far back as 1910 and had been intimately connected with the affairs of the Sopwith Company—particularly the technical affairs relating to design and construction. He had been responsible for the design of one of the first British machines to win the Schneider Trophy. His wide experience would enable him to speak with special authority on the technical aspects of the production of aircraft. The Society was particularly glad to welcome Mr. Sigrist as a lecturer for the first time before them.

Mr. SIGRIST: The use of the word "Production" in connection with aircraft to-day is almost a misnomer, as circumstances are such that aircraft (and where throughout this paper I use the word aircraft, I refer to the structure and equipment minus the engine), are constructed rather than produced.

The industry works under conditions peculiar to itself, and whereas the mention of production in connection with kindred trades usually implies close association with the word "mass," I prefer to regard the term when applied to aircraft to mean the economic utilisation of space, men and material. It may be that in the distant future our output will be comparable in value if not in numbers with that of the motor trade, but I am afraid I shall not be a participant in those halcyon days. The ever present problem is not exactly how to produce aircraft, but how, under present conditions, to produce on an economic basis.

I do not propose to describe in detail the various processes entailed in constructing aircraft, as that is a subject which can only be adequately dealt with at length, but my object is to discuss in broad terms the question of

production as applied to aircraft, and endeavour to explain some of the difficulties in connection therewith.

If I occasionally digress or approach the sacred realms of the designer, it is by way of explanation only. It is an economic axiom that the full benefits of output are only realised when there is a steady flow of work over a period. Owing to the vagaries of the Air Ministry, bad luck, dud engine, or unforeseen circumstances according to the individual opinion, the unfortunate constructor is seldom able to benefit by such a period. For six or nine months he may be very busy, even working overtime, and then finds a sudden slump. In other words his year is made up of a period of high peaks and depressions, a factor which bears an important relation, among other things, to the price question.

In the construction of aircraft no less than sixteen distinct classes of craftsmen are employed. This is apart from the technical and administrative organisation, and to weld such a widely separated group of labour into a productive unit is in itself no small achievement. Roughly speaking, 45 per cent. is skilled labour, 35 per cent. semi skilled, and 20 per cent. unskilled, but it is necessary, no matter what his degree of skill at his particular calling may be, for the newcomer to the aircraft trade to receive instruction to some extent. The labour position, therefore, is one needing continual thought. The constructor during periods of slackness, usually endeavours to retain the nucleus of his skilled complement, and work restricted hours, but this is not a satisfacory proceeding inasmuch as the better class of men invariably look for a situation in a more stable industry. It is a perturbing feature of the production problem, as once a man leaves the industry he loses touch with developments.

I will deal firstly with the question of experimental production. I think it will be generally accepted that experimental work is a costly and long drawn out process. Partly this is due to design delays, to a lesser extent to material delays, and to a greater extent to alterations in specification requirements. At the same time it is possible to cut down experimental costs by the exercise of a little care. Drawings should be issued in such a sequence as to ensure that under reasonable circumstances there will be no delay in assembly through non-manufacture of components. Once a skeleton structure is erected, the progress of the detail lay-out is facilitated. I endeavour to obtain drawings of experimental machines in the following order :—

(*a*) Fuselage.
(*b*) Main planes and centre section.
(*c*) Engine mounting and bulkhead.
(*d*) Tanks.
(*e*) Flight controls.
(*f*) Tail unit.
(*g*) Undercarriage.

Cowling is a job which is always carried out better on the machine rather than to drawings, and the disposition of the equipment and other details can always be simplified when the actual structure is available. To progress experimental work is difficult unless there is a deviation from the usual routine. I find that the most successful method is to make one individual responsible. He can be on either the works or drawing office staff, and it is his duty to receive drawings, check material quantities, requisition any required, and follow the job to its conclusion, dealing in his capacity as liaison between design and manufacture, with all queries as they arise. This liaison, if properly carried out, can be of invaluable assistance.

The man engaged on experimental work should be a capable craftsman, and preferably one with more than a superficial knowledge of aircraft. The foreman should be capable of positioning fairleads and other details without

reference to the designer, and should be given a certain amount of latitude in dealing with cowling arrangements and the like. It is not advantageous to carry out experimental jobs on a piece work basis, and it is better to offer an additional inducement in the shape of an ability rate or experimental bonus. Lack of material is a common cause for delay, and whilst at times it may be unavoidable, a little thought on the part of the designer in the selection of sizes and specifications would be of assistance.

The liaison officer, on receipt of drawings, should extract material quantities, ascertain what is available from stock and earmark accordingly. If the material to be ordered is of such a nature as to cause delay it is worth while endeavouring to effect a compromise with the design side whereby stock, or material which is available immediately, can be substituted. There is no gain in over ordering material for experimental work, as although one naturally endeavours to use parts which have previously been made, the scope is somewhat limited, and the inevitable result is that in time there is an accumulation of short ends and pieces for which there is no economic outlet. Collaboration between the design and experimental departments on the material question may result in the laying down of certain standards which will result in economy. For instance, I have found that there is an appreciable saving in the use of stainless steel sheet (D.T.D. 42H. or D.T.D.57) as a substitute for high tensile sheet (S.4) on fuselage and wing fittings purely on the heat treatment question. Duralumin tubing for ribs has proved costly and difficult to obtain even when required in quantities, and it is cheaper to design for strip, despite the additional cost of rolling or drawing to section.

It is essential to complete experimental machines in every detail at the works before sending for test. Costs amount at an alarming rate when outside work becomes necessary, and precautions must be taken to keep in touch with all that is being carried out. During progress of the work the liaison officer keeps all data, so that in the event of a further order any snags which have occurred can be rectified or discussed before the issue of production drawings. The difficulties to which I refer under the heading of " alterations or modifications in specification requirements " are difficulties with which most of us are only too familiar. I cannot offer a solution of this problem. I can only sympathise and say that as modest laymen we cannot be expected to understand the considerations of high strategy and tactics which dictate these requirements and any criticism would therefore be ambiguous.

When an experimental type is accepted for service the question of production procedure calls for consideration. It is impossible to lay down hard and fast rules as so much depends upon the individual concerned, the type of machine and quantity ordered. The constructor should endeavour to ensure an even balance throughout the whole of his factory so that starting from the raw material stage each section completes its quota of finished components in time for the erection to commence and carry straight on until the order is completed. I regret to say that this ideal is seldom attained. Service modifications, internal alterations, and delays in obtaining supplies of material are responsible for the majority of failures. Naturally the question of balance in departmental output is an administrative one, but it is to some extent swayed by the manufacturing methods adopted.

Before the issue of production drawings there should be a discussion between all concerned, and it is at this discussion that the data in possession of the liaison officer will prove useful. Wholehearted collaboration and constructive criticism help considerably towards rapid and consequently economical production, and the time spent in settling the main layout is amply repaid. The actual responsibility for the administrative organisation is of course a question for each firm to consider from its own viewpoint. For my own part I regard

the planning department, under which come the progress and ratefixing sections, as the hub of the works. Their duties commence with the receipt of drawings. From these they extract material quantities and requisition to the stores. They process operations and plan the issues of orders to the shops, decide the number and design of jigs and tools, fix piece work prices and progress to the scheduled requirements. Every alteration or modification must pass to the works *via* this department, and they deal with any queries which arise. By this means the foreman and chargehands are relieved of the routine work, and are free to devote their energies solely to the question of output. Efficiently run, this system is economical and simple, and although in actual practice the scheme does not always function to schedule, the fault is mainly through modifications and scrap.

The question of output is to a large extent bound with that of design—and we all hold more or less very decided opinions as to the best method of design for production. Personally I am not prepared to advocate any particular system as outstanding, but I do believe that each individual type of machine requires considerable thought from entirely different viewpoints when being detailed for production, *i.e.*, the purpose for which the machine is required must to a great extent decide the main constructional features. The detail, however, invariably offers some measure of scope for design purely for production, and this opportunity is not always appreciated. In some cases there seems to exist what might be termed a "machining complex." In other words there seems to be a feeling that machine shop work is expensive and uneconomical when compared with sheet metal work. It is almost entirely a fallacy, but each case must, of course, be judged on its merits.

Where a machined part can be substituted by a pressing, then do so, but if the choice lies between a complicated plate fitting and a machined part it is usually advantageous to use the latter. Particularly is this the case where drop forgings can be utilised, as providing the machining layout is suitable, costs, despite the addition of tools, will be comparable, and the job will be infinitely better. A piece work system should be applied to all production work as apart from experimental. It is welcomed by the men, and if run on a proper basis stimulates output. In the actual manufacturing processes, the proportion carried out by skilled and semi-skilled labour depends upon the extent to which jigs and tools are utilised, and this is a factor for consideration when deciding what are to be made, *i.e.*, an increased expenditure on tooling may save much more than a corresponding amount on construction costs.

In the material field there is a very wide scope for selection, and consequently opportunities to economise. It is advisable to adhere to material and sizes which are available from stocks or which can be obtained quickly, as delay may disorganise the production schedule entirely. A percentage should be ordered over and above requirements to replace scrap. Such items as bar, sheet and tubing do not call for special comment, except that the former should be obtained wherever possible in the bright condition. There is a negligible difference in price, which is more than balanced on tool costs. Tubing should be ordered in the actual lengths or multiples thereof required. Sand castings in non-ferrous metal (except phosphor bronze) should only be used on a production order as a last resort. They are costly owing to the difficulty in obtaining sound and non-porous castings, a fact which is not usually discovered until a certain amount of machining has been carried out. As an alternative one can use a duralumin stamping, a chill die casting, a pressure die casting, or a hot stamping, according to the nature of the job. The initial cost of dies is not great when spread over a quantity, machining costs are lower, and the part is more satisfactory. It is, of course, necessary to arrange for material to be delivered to a schedule in order that machining and fitting operations can

be done in batches. Assembly should as far as possible be by units, and planned on the assumption that each unit when ready is a complete group. Once the fuselage is in skeleton an endeavour should be made to arrange for the interior fitments, pipe lines, controls, engine, tanks, etc., to be assembled on a time basis. In other words it should be possible to sub-divide the operations to such an extent as to allow the structure to progress once every few hours for a different assembly. Thus there is one gang of men only at any one time on

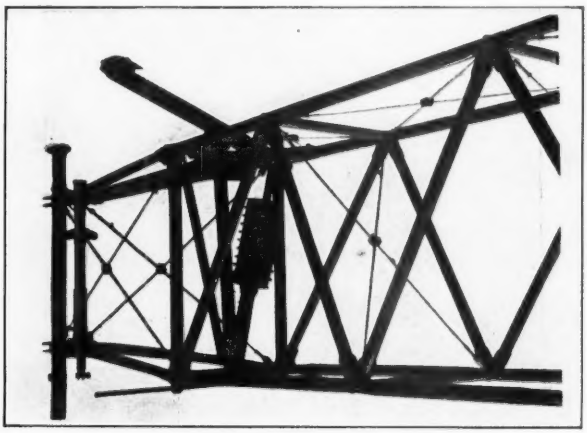


FIG. 1.

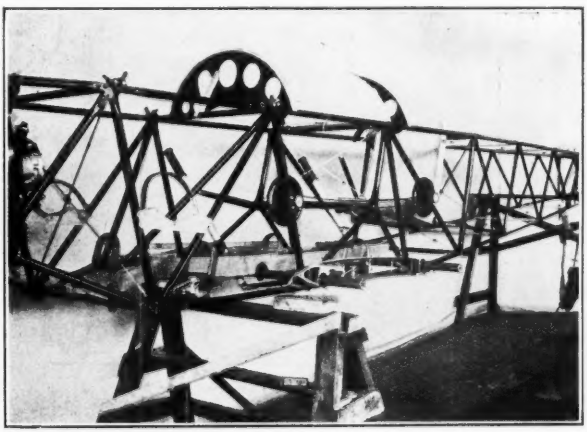


FIG. 1a.

the job, and no overlapping. Covering and doping operations do not offer any difficulties and the machine should be completed in all details before sending for tests.

Whilst it is not my intention to comment upon or criticise shop practice or manufacturing processes as employed in individual cases, I wish to discuss briefly some aspects of production methods generally and to this end I propose to describe some of the methods employed by my own firm on main details.

I would ask you to bear in mind that it is the manufacturing aspect only I am discussing and not the design features.

You are all probably aware that for fuselage construction we use steel and/or duralumin tubing throughout. The arrangement is shown in Fig. 1 and Fig. 1A and the detail joint in Fig. 2. The construction is quite simple and self-explanatory. The squaring or flattening operation on both longerons and struts is carried out in a rolling machine. The

FIG. 2.

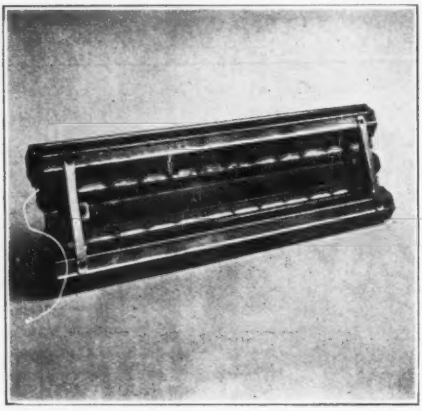


FIG. 3.

operation can be by hand or power, and takes a few minutes only. The diameter is fairly important, but the length of the flat is immaterial. The flitch plates are a pressing, and from a range of six tools plates are available for machines between a light aeroplane and a day bomber. The rivets are of steel tubing and can be to Specification T.5 or the lower grades. Stainless rivets are available and spin quite easily. The cupped bolt which takes the cross strut is a plain capstan job, and the wiring plates are pressed. Four tools will supply a very wide range of wiring plates, and should cover practically all requirements. The assembly jig for the sides is very simple. For either experimental or production a layout board or boards only is required. The strut

tubes can be cut off either before or after flattening and jig drilled ready for assembly. The final erection is straightforward, and the whole operation, except for truing up, can be carried out by semi-skilled labour.

The question as to which is the best material, shape and section of the main spar is a matter involving design considerations, and is a subject which can give rise to much controversy. Personally, I consider that the fundamental basis is the purpose for which the machine is required. In some cases duralumin offers a satisfactory solution, in others steel. My experience is mainly that of the latter material, and the types of spar we are producing are shown in Figs. 3 and 4.

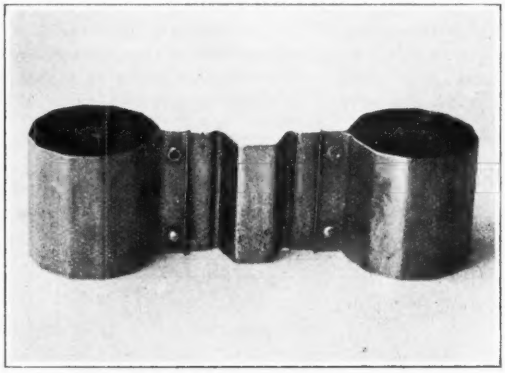


FIG. 4.

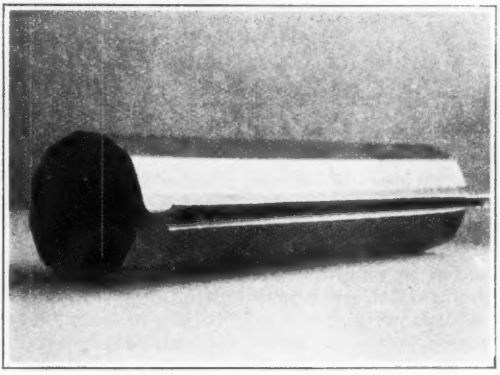


FIG. 5.

The material is high tensile steel strip, rolled in the hardened and tempered condition. The booms come from the rollers practically dead straight and fit into the assembling jig without difficulty. The jig itself consists of two steel bars on to which the booms are clamped together with the connecting web. A travelling punch pierces the holes, and the rivets are inserted by hand, and headed with a travelling riveter. The punch must be kept clean and sharp, otherwise there is a tendency for the material to tear or crack. Drilling might be more satisfactory, but would be a more complicated operation. The labour employed on this assembly is unskilled and has proved quite suitable. I am at the moment

contemplating experiments with a view to speeding up the assembly operations on the automatic principle, but I doubt whether the results would warrant the expenditure.

A certain amount of experimental work was necessary before the rolling operation was successful, but once the initial difficulties of roller shapes and numbers had been overcome the job was simple. Provided the strip is flat, the boom comes from the machine as shown in Fig. 5, and no final operation is necessary to close it on to the web. In view of the success attained with this method we have not attempted to use softened material and harden and temper after rolling. It is probably advantageous to follow out this method when a built-up spar of different section is used, and I believe Mr. J. D. North has been very successful in this direction. I do not think it necessary, or for that matter very practical, to have an automatic rivet feed on the assembling operation, as it can be done by hand quite easily. The spar with the flat-sided booms is better for rib attachment than the spar with the corrugations, but the latter is slightly

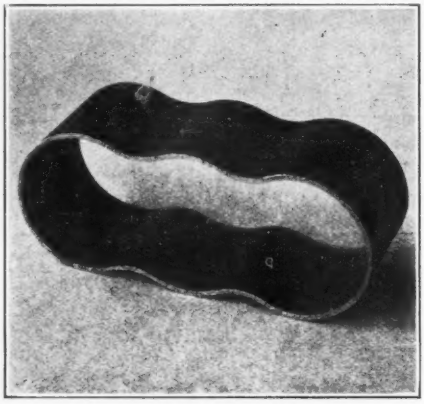


FIG. 6.

stronger. On small machines the drawn tubular spar, as shown in Fig. 6, is cheaper and just as simple from the attachment point of view. In production it offers the advantage of being ready for use without manipulation on the part of the constructor, but its advantages over and above a small machine are outweighed by the increase in weight. A duralumin spar of this section is initially more expensive than a steel spar, and although of thicker gauge is slightly advantageous as regards weight. It is difficult, however, to obtain perfectly straight in long lengths.

The type of rib depends to some extent on the type of spar. We have used ribs of duralumin tube, strip, and aluminium sheet. The tubular rib is on the whole slightly lighter, but the material is costly. It is impossible to obtain tubular rivets in the smaller sizes, and if solid rivets are used, care must be exercised during the operation, as the tubing being of thin gauge is easily damaged. The strip rib is cheaper both as regards material and manipulation. The section can be rolled or drawn without difficulty, and riveting is a simple matter. The pressed aluminium rib is attractive, but has a limited application. It is slightly heavier, but if the quantity is sufficient to warrant the cost of a pressed tool it is cheaper. I have not experienced any difficulty with cracking during the flanging operations, neither has it been necessary to heat-treat in any manner. Purely as a personal opinion I prefer the wooden rib, and I see no

reason why it should not be used with metal spars. It is cheaper than any other type, and the combination should result in a very efficient unit.

Tinned steel tanks are a straightforward job, and do not as a rule offer any difficulties. If the quantity is sufficient, press tools can be utilised for the shell and baffles, and the whole can be jig assembled. Aluminium tanks naturally require more care and attention. We have used tanks made in this material and in duralumin. The former have been either welded throughout, or welded at the tank ends only, the baffles being bolted in with heldite compound as a jointing material. This does not sound very satisfactory, but the results have been surprisingly good. The duralumin tanks have been riveted throughout with the same jointing substance, but whilst giving equal satisfaction, were more expensive. The jointing material does not affect the anodic protection. With a little instruction female labour is quite capable of welding aluminium successfully, and with experience produces a very neat job.

The question of protection against corrosion has assumed importance of recent years. The anodic process as applied to duralumin is now in common use and does not call for any special comment. I have not heard of any satisfactory process of reclamation, but I understand research is leading towards this end. It may be useful to note that we use rain-water for replenishing the solution. I do not know whether our particular brand of rain differs from others, but on analysis it has proved suitable. For steel fittings we find the cadmium process is better. It is slightly more expensive than the zinc, but the resultant coating is more satisfactory, and although I am doubtful of the real value of the oil treatment, I believe it does improve the corrosion-resisting property. Whether cellulose or stoved enamel is better is a matter for individual consideration. It is safe to assume that the protective qualities are equal, and opinion is divided as to which finish is more pleasing. The enamel is cheaper in the first cost and covers a greater area. Against this must be set the fact that the cellulose does not require stoving and can be handled earlier after application. We use both processes and find that the cellulose is more economical, but we cannot use it exclusively owing to insurance considerations.

The chromium process is not extensively used in the aircraft industry. It is similar in operation to the cadmium process but is more expensive. It would probably be cheaper than cadmium plus cellulose but less efficient.

The inspection question is one which can be responsible for difficulty and delay unless organised on a sound basis, because it is a department where either or both the man and the system can be at fault. No one will cavil at the necessity for a careful and systematic inspection of aircraft, but there is a tendency not exactly to magnify the importance of the operation, but to interpret rigidly and literally a series of regulations and limits which are in the majority of cases unnecessary and too severe—a fact which hampers production and initiative. Interchangeability is of course the most important feature, and providing this requirement is complied with, more discretion should be allowed to the inspector.

At present it is practically impossible for the detail components to be inspected at the same rate as they are produced. I do not suggest elimination of all the detail inspection, but a relaxation of rules and a revision of limits—some of which are of course imposed by the designer—would be of considerable help. We have a system whereby a responsible official discusses the rejects with the chief inspector once or twice weekly. If parts offer a chance of salvage they are sent to a rectification bench and re-submitted. Quite a number are thus rendered useful, and an atmosphere of discretion is created without encouraging a careless tendency.

The question of plant is rather one for individual consideration, as so much depends upon the type of production and financial and other factors. It is difficult during the present transition stage from wood to metal to decide the most suitable type of machine tool in which to invest. A machine which is not working to its

capacity is losing money, and whilst the obvious need is a machine which is useful on every possible occasion, it is difficult to avoid the purchase of plant which is useful on experimental work but subordinate on production. Economically, a well-balanced plant is essential, but as each concern differs in many fundamental factors it is impossible to make any general recommendation.

Special purpose machines are usually made to the constructor's own design and cover a variety of purposes. In Fig. 7 is shown a rolling machine on which we have carried out a number of operations from the rolling of strip spars to slot aerofoils. This machine is an adaptation of a standard type and has been quite satisfactory. We are now constructing a machine embodying certain improvements as the result of our experiences. The rollers for experimental and light production work are of ordinary cast iron and are both cheap and good. For extended production we use a special nickel-chrome iron roller cast to shape. This is quite machineable, retains a hard surface and is cheaper than steel.

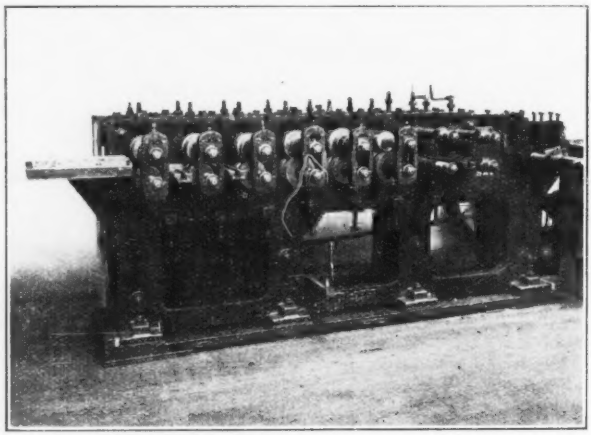


FIG. 7.

Fig. 8 shows a streamline wire rolling machine which was made to our own designs—not with the idea of competitive manufacture, but to meet our own requirements. It has proved a good investment and we produce wires which come off practically straight. The secret of success lies in the use of rollers of suitable diameter and the regulation of pressure and passes. The rollers are of chill cast iron ground and lapped. They have been in continuous use for over two years without showing signs of wear, and two sets supply all sizes between 1/4 and 9/16.

Of the smaller tools such as riveting, welding, bench cutting, filing appliances, etc., there are a variety available, all of which are good. The question of riveting is important, as it is an operation which is increasing. The type of tool used depends entirely upon the design and accessibility of the component to be riveted. We regard the operation in order of merit from the production side as " squeeze," " hammer " or " spin," and by unskilled labour wherever possible.

The care of machine tools is a matter of some importance. We allow the usual time at the close of the week for cleaning, oiling and greasing, and in addition the chief millwright makes a periodical inspection for signs of wear. The maintenance of efficient work more than pays for the time spent in this way. Such minor points as the selection of the most economical cutting and lubricating oils, the use of oil separators, etc., have collectively some bearing on production

costs, and the removal and sorting of swarf and scrap ends is worth a little attention. We find that it pays to clear machines frequently and bin all scrap into separate labelled compartments, thus obtaining full value for each metal. When purchasing small tools, quality should be the first consideration. There is bound to be a certain amount of wastage and breakage, but generally speaking aircraft materials call for the use of small tools of corresponding quality. It may be worth while, but not perhaps practicable, to contemplate a scheme whereby the best tools are issued to skilled men only. To some extent this is of course automatic, as the jobs calling for such tools are mainly in the hands of the skilled man. We have all tool re-grinding and renovations carried out by one small department only, as this enables the work to be done correctly and

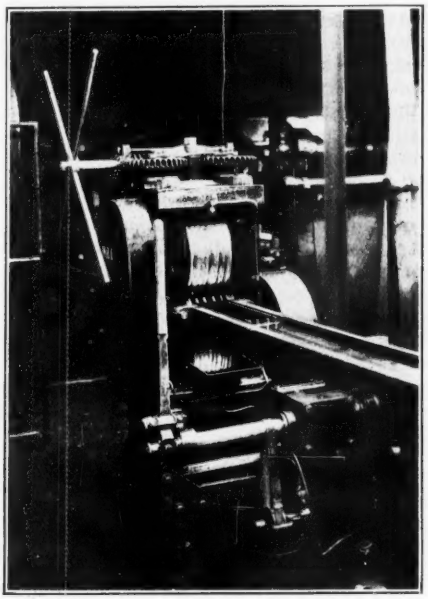


FIG. 8.

expeditiously. It is advantageous to use one brand of high-speed tool steel only, as this avoids the necessity for different heat treatments, and it does not matter if tools become mixed.

Stores should be arranged according to the general factory lay-out and system, and the issuing clerk should be a person wholely conversant with the material he issues. We employ presumably the same approved system as others of marking bonded material, and do not experience any difficulties. The use of stores' runners is a good practice, and the men should be encouraged to requisition their requirements for one job at the same time.

I should like to refer briefly to the question of production in emergency. This subject has a vital bearing on the question of production problems and is one which has been discussed at length by more competent authorities than myself. It is common knowledge that the Staff view of aerial warfare is that in the first clash of hostilities casualties in machines and personnel will be heavy, and the side which can most rapidly re-equip will be the predominant party. In other words, the industry must be in a position to assume the rôle of a third

line of defence. Frankly, we cannot accept this to-day, and until we are on a basis which ensures continuity of output, and obviates the high peaks and depressions which are now prevalent, the position will still be serious. Imagine a sudden call under present conditions—a call for, let us say, one hundred varied machines within seven days, or even fourteen. The chance of more than a 30 per cent. response is remote. Let us go further. How soon could we attain an increasing output up to two hundred machines per week? Consider the material position—and the possible area of hostilities—and it will be a difficult question to answer. We cannot expand immediately, neither can we find sufficient men to instruct allied trades which might be of assistance. Even if we did manage to produce the machines, the engine question would still remain, and in its way seems less capable of solution than the aircraft problem.

I realise that political and economic factors and a natural hesitancy to undertake extensive commitments in face of the rapid advancement of the science of aerodynamics and engines must be largely responsible for the Air Ministry production programme, and whilst I sympathise with them in their difficulties, I rather feel that the subject has not received the consideration which its importance merits.

That much of our energy is directed toward military aircraft is undeniable, but we must not lose sight of the fact that military aircraft is essential to our Empire, more so than in the case of any other nation, and if the firms specialising in and contemplating commercial aircraft are less than those on military aircraft, I see no reason for adverse comment. It maintains a balance and is sufficiently competitive to encourage progress without deteriorating into a price cutting or quality reducing campaign. That we have not been able to considerably assist our home production by foreign orders, especially in the military market, is regrettable but not entirely our own fault. The facts are quite plain. Our prices are high in comparison with those of our competitors and our markets are limited. It is admitted that for quality, performance and reliability we are superior, but it is difficult to make the customer realise that these advantages are worth the additional expenditure. It is my experience that in dealing with the potential foreign buyer one has to explain among others such things as why it is that competitive machines always possess higher factors than British machines. This illusion needs a lot of explaining and the I.C.N.A. might include in its activities a discussion on standardisation of stressing.

The factors which influence the price question are well known, and that markets are limited is entirely due to financial considerations, tariffs, and the national viewpoint of the foreigner, who, as in this country, demands that his own money be spent on his own industry. Where there is an opportunity we can show a good record, and with the increasing world-wide realisation of the importance of the aeroplane and the part it will eventually play in our daily life I think that the demand will sooner or later enable us to meet in some measure the biggest of our problems.

Discussion

Mr. J. D. North : There was very great difficulty in dealing with the subject of aircraft production, because it involved two entirely different considerations, one being the necessity for economical production of the number of machines which manufacturers were called upon, or hoped to be called upon, to manufacture in times of peace, and the other the production of machines on the enormously greater scale which had been shown to be necessary for the prosecution of a first-class war. When a manufacturer sought guidance as to his future policy he found these two considerations in conflict. There were great advantages in being able to design for very large mass production; it threw open a very much wider field of engineering resources, and undoubtedly made it possible to produce better aeroplanes. On the other hand, to instal plant sufficient to enable

enormous production to be achieved, but to be unable to use that plant, was very expensive. The works practice of Messrs. Boulton & Paul followed very closely that described by Mr. Sigrist. In experimental work there was some advantage to be gained by introducing piece work, if one could have a standardised form of operation, and Messrs. Boulton & Paul had been able to introduce a fair amount of piece work with advantage. With regard to the supply of materials, he suggested that it would be advantageous, instead of putting a drawing office man in liason with the works, to put a man from the works or planning department in liason with the drawing office. He would be able to keep a check of the discriminate use of materials, and would have the opportunity of arranging for the ordering of materials earlier than would be possible if he had to wait until the drawings had passed the planning department. Referring to Messrs. Boulton & Paul's continuous heat treatment process, he said they had applied it to as much as 30 or 40 tons of steel strip and were certainly of opinion that it was economically advantageous. Among other advantages, it had enabled them to make a spar consisting of two elements and without any rivetting at all. They had adopted the practice of rivetting spars in preference to punching, because they had found the former to be the more economical operation, but much depended upon the design of the spars. A semi-automatic rivetting machine was used, and they had found that it was not worth while attempting to use any automatic device for inserting the rivets. He heartily endorsed Mr. Sigrist's remarks with regard to the machining complex; it was a relic of the old days when aeroplanes were built in sheds, and it died very hard. Surely it ought to be agreed among engineers that there was no cheaper class of manufacture than that of machining with first-class machine tools; for aeroplane work, first-class machine tools were required, and it was false economy not to use them. The experience of Messrs. Boulton & Paul with sand castings had not been so painful as that of Mr. Sigrist, probably because they had their own foundry. The importance of discrimination in inspection should not be lost sight of.

Major H. N. Wylie: In discussing the problem of so organising the industry that a very large output of machines could be achieved in the event of war, he referred to the difficulties experienced during the last war in securing supplies of various materials. It had been his duty to ascertain why these materials were difficult to obtain, and to endeavour to accelerate their production or to find substitutes. When there was a shortage of timber he had had to consider the substitution of other materials. The first proposal was to substitute high tensile steel tubes, and it was the intention to use them in the construction of a large day bomber, but it was found that the total number of high tensile steel tubes that could be made available was not more than half the number required for that one machine. Duralumin tubes were then considered, but the possibilities of producing them in sufficient numbers were very little better than in the case of high tensile steel tubes. He had then considered the use of low tensile steel tubes having a tensile strength of perhaps 50 tons per sq. inch, and had found that the prospects of production in that case were considerably better. Tubes of 50-ton steel might fulfil the schedule for one type of machine. The material which had offered most promise, however, was steel strip, and steps were taken to manufacture spars from this material. The proposal was to use, not high tensile steel, but cold rolled steel strip having a strength of about 40 tons per sq. inch. The strip could be made in large quantities, and the spars made from this material would not weigh more than the rather low-grade wooden spars being largely used at that time. His anticipations were that in the next war—if there be one—we should not have a very large output of machines with metal coverings; the covering of the wings at any rate would require to be of fabric, because the output of thin duralumin sheet for covering wings could not be increased rapidly enough. Supplies of dura-

lumin would probably be very restricted, as was the case during the last war; if the construction of an airship were contemplated at that time there was no duralumin available for aeroplanes.

Discussing the difficulty of obtaining small duralumin tubes which had been referred to by the Author, he said that during the war duralumin tubes were not made of less than ½in. diameter and thinner than 20 gauge, and small steel tubes were also difficult to obtain.

Steel tubes were readily enough obtained in small sizes at the present time and were readily obtainable before the war.

The thinnest tubes made by the hot rolling process are about ¼in. thick and the thinner gauges are produced by a process of cold drawing, so that the larger sizes are the raw material for the smaller sizes.

When demand exceeds supply and tubemakers can dispose of the large sizes as such, there is a strong temptation to fulfil orders for these, rather than to keep them in the works for a week or so longer while they are being slowly reduced in size and thickness.

The result is that small thin tubes are not obtainable in large quantities when the general demand is suddenly increased.

Since large thin tubes and small thin tubes would be unobtainable in large quantities, it would be necessary to use steel strip in place of these. Even at the present time it was easier to obtain this in the soft state than hardened and tempered, and his firm used it in the soft state and heat treated it after it had been formed into sections.

Special plant was necessary to heat treat the strip either in the flat or as formed sections, and he considered that, in the event of a sudden expansion of demand, only the more important parts would be of heat treated strip and the remainder would be of strip which was given a strength of about 40 tons per square inch by cold rolling.

Mr. A. E. L. CHORLTON: He would like also to stress the importance of being able to increase enormously the productivity of existing works in a time of national emergency. The difficulty of obtaining materials during the last war had been so great that in the last two years or so projects had been advanced for the constitution of a special alloy steel plant to supply material to the aircraft industry. If it were believed seriously that there would be another war—he had thought there was not going to be another—it was important that something should be done to ensure supplies of the necessary special steel; he did not think supplies could be obtained by ordinary means. The steel required would be of still higher quality than that used during the last war, so that this project was one worthy of consideration. Apart from the structure of the machine itself, the limiting factor in the production of an aircraft as a flying machine was the engine, and in connection with the engine itself there were factors of detail which might limit production. For instance, in the case of the multi-crank engines used in the last war, the crankshaft was the limiting feature. Very large quantities of nickel-chrome crankshafts had been ordered from America, and the first deliveries had failed badly owing to cracking. The consequences of such happenings at a time of emergency, when large numbers of military machines were required, were far-reaching. Emphasising the importance of continuity of production, he said that the Air Ministry's present methods of ordering aircraft were such that the periods of construction covered by the orders were too short to allow of any continuity, and efforts had been made to have three-year schedules arranged, such as those adopted in the old Naval days. In those early days it was realised that it was bad policy to order things day by day, and a programme was spread over a period.

Major G. P. BULMAN: He would like first of all to point out that he was no longer connected officially with inspection. He suggested in regard to the matter of limits, that the designer himself was best fitted to widen them; it

must be common ground that limits should not be based on the closest dimensions to which parts could be made under the best conditions, but should provide the greatest latitude consistent with the safety and efficiency of the product; in aeronautical construction the factor of overall weight must have an influence no less than questions of actual strength, bearing area, etc. Having increased the limits to the absolute maximum, there must still surely, however, remain need for an inspection organisation to ensure that those limits were not exceeded.

With regard to production, again the designer could exercise considerable influence and could do much more, if, in addition to discussing design and lay-out in his own works as recommended by the author, he would consult also, for instance, the drop forger and the foundryman, who must clearly have far greater experience in the difficulties of production of forgings and castings than the aircraft designer himself. He (Major Bulman) had always found that the material suppliers were thoroughly anxious to help but very often were somewhat diffident about putting forward suggestions uninvited for the reason that they recognised their own lack of knowledge in aircraft construction and felt, therefore, that their suggestions might not always be welcomed.

Squadron-Leader KILLMAYER: He endorsed Mr. Sigrist's remarks on the importance of continuity of production, and agreed that the series of peaks and depressions in the production curve reacted very unfavourably, not only upon the industry, but upon the service itself, because it enhanced the costs of production, which resulted in a dissatisfied industry and a dissatisfied service. It was very difficult, however, under existing conditions, to suggest a remedy, and at the present time he could not see how the difficulty could be overcome.

Mr. S CAMM: He pleaded guilty of possessing the "machining complex," and said that surely it would be cheaper and better to design parts which could be made by simple pressings from sheet metal than to demand drop forgings, because these latter could be better applied to the needs of the engine constructors. During the late war it was found necessary to obtain engines for some machines from abroad because the engines for which these machines had been designed could not be produced in sufficient quantities or within a reasonable time. It was possible that a good deal of the delay in engine production may have been due to the fact that drop forgings had been applied to much of the other parts of the aircraft.

Mr. F. HANDLEY PAGE: The paper dealt with a very important phase of aircraft work, and one which was very little understood. Aircraft is produced and would continue to be produced for two purposes, *i.e.*, as instruments of war and for use commercially, and in time the production problem as applied to each of these would call for the application of entirely different methods. That tendency was already apparent in America, where commercial aircraft were being produced in factories quite separate from those producing military aircraft. For example, the Curtiss Company manufactured their military aircraft at Buffalo, and had started an entirely different factory at St. Louis for the manufacture of civil machines. The reason was not far to seek. A manufacturer must make his commercial aircraft to sell in competition with those made by other manufacturers, and which gave a certain standard performance. He must design them with due regard to cheap production, in the hope that eventually he would be able, by salesmanship, to create a mass demand so that he would be able to manufacture cheaply by mass production methods. With regard to military machines, he had yet to find, on the part of our own Air Ministry or any of the governing bodies dealing with these matters in any country, any sort of mass demand; he was not referring to a mass demand for the types of aircraft made, but a mass demand of requirements. A military aircraft must have its compass perhaps half an inch further to one side, its air speed indicator a quarter of an inch the other side, the stick used for a single-seater fighter was such that it was totally impossible to use it for a two-seater bomber, and so on; therefore,

it was necessary to build a whole range of types, which could not be built on a mass production basis, and the methods of production of such machines were more like day-by-day jobbing than manufacture. To be successful in a war which demanded the use of large numbers of machines it is necessary to recast ideas entirely, for mass production would be essential, but could not be attained unless there were unity of ideas and demand so that a simple specification could be arrived at. On the other hand, if a few aircraft of superlative quality were required, with which to lay out the Prime Minister, the whole of the Cabinet and the whole of the directing forces in an enemy country, then mass production was not necessary. For that purpose only a few aircraft were needed, the right kind of aircraft at the right time, and that consideration led one to think that in connection with military aircraft it might be better not to think of mass production as normally understood in regard to commercial aircraft, but to continue to produce military aircraft on lines somewhat similar to those adopted to-day. In spite of that, however, there were many points raised in Mr. Sigrist's paper to which attention might well be devoted; for instance, his very simple and ingenious method of fuselage construction, and methods similar to that, must be studied if cheap aircraft were to be made. In addition, means must be studied whereby everything could be made by machine rather than by human labour. So long as the actual operations were carried out by the machines, and human labour was confined mainly to directing the operations, relatively high wages could be paid, because the machines themselves would be responsible for most of the cost. To do that standard methods of manufacture of detail were necessary, and Mr. Sigrist's idea of having a limited number of stampings from which to make a complete machine was an extraordinarily good one. If the Air Ministry could be persuaded to issue a sort of "Meccano" of standard parts, one would know exactly from what parts an aeroplane must be built, and the ingenuity of the designer would be exercised in determining into what profiles he would be able to build the parts and make a standard fuselage. Then it might be possible to achieve the ideal of attaining real mass production in time of war. The paper provided a good deal of food for thought, and offered some solution of the intermediate problems which face us to-day.

Dr. A. P. THURSTON: He had always been impressed with Mr. Sigrist's genius for organisation; the machines produced by him had always been recognised as being models of efficiency and models from the point of view of effecting mass production. Therefore, it was disturbing to hear him say that in the event of a sudden emergency it would be impossible for the industry to expand, and the matter was one which should receive the attention of the authorities. He agreed with Mr. Sigrist that something should be done to secure international agreement in regard to the stressing of aircraft. If it were British to be pessimistic as to our own performances, then truly we had been most British with regard to our load factors. The load factors laid down were the minimum which could occur in the event of a considerable number of contingincies which were not likely all to occur together, and the result was that our calculated load factors were always at least 1, 2 or 3 less than the actual load factors of the machines. On the other hand, he had calculated the load factors on many of the leading foreign machines, and had found that foreign designers erred on the side of optimism. Thus, the position was most unfair to British manufacturers. Mr. Sigrist had put forward a splendid simplified construction of fuselage which would lend itself readily to mass production, and he himself, had been extremely impressed by the reasoned detailed account of the processes adopted in a highly specialised and extremely efficient works.

Captain W. H. SAYERS: He expressed the gratitude which the aircraft industry undoubtedly owed Mr. Sigrist for his very courageous and frank statement as to the position which would arise in the event of a sudden demand. That aspect of the question deserved to be stressed much more than it had been.

Mr. W. P. SAVAGE: He had been associated with both the manufacture and the inspection of aircraft, and if, as suggested by Mr. Sigrist, more discretion were given to an inspector the inspection authorities would be faced with the difficulty of legislating against the mis-use of that discretion. He would prefer to give more discretion to the designer. At present, if a small error were made in the shops or a small modification were necessary, and if the drawings already bore the approval signature, it is necessary to go through the multitudinous requirements of the official modification procedure to get further approval of the proposed alteration. That increased costs far more than did the difficulties which arose from inspection, or the rigid enforcement of inspection rules. He would suggest to the A.I.D. authorities that they should empower the designer to alter his design, within reason, without reference to other authority. The designer had to take the responsibility for the design, and if a hole needed to be moved, say, 3/16in. from the original fixed position, surely no one knew better than the designer whether that could or could not be done with safety. Discussing the problem of preparing for the next national emergency, he suggested that the first thing that would be done was to revert to composite aircraft; in his view circumstances would dictate that policy. Whilst there were obvious advantages in having the main structure of metal, it would be an added advantage—and he was pleased to note that Mr. Sigrist agreed—to have the secondary structures, such as ribs, flooring, instrument boards, fairings, etc., made of wood. As the result of such a policy our wood shops would be kept going, and there would be no scrapping of machine tools which would be wanted in the future; further, a nucleus of skilled woodworkers could be maintained. There were other advantages in composite aircraft. For instance, the problem of maintenance and repair was of very great importance at a time of national emergency, for, if the centre of operations were far from the source of supply it was a distinct advantage to be able to splice in a piece of timber on some part of the aircraft rather than to repair a steel component, the material of which was subject to workshop processes which could not be carried out at an advanced base. Further, a greatly reduced quantity of spares would be required to be carried. Discussing the factors which influence price, Mr. Savage admitted the necessity for the inspection of aircraft, but pointed out that our elaborate system of inspection increased costs considerably. Some two years ago he had had the opportunity of investigating the costs of manufacture, in a foreign factory, of machines which were identical with those being produced in the works with which he was associated. He had found that the cost of the foreign-built aircraft was about 65 per cent. of the cost of our own—the difference being due largely to the absence, not of inspection, but of inspectors, in the foreign factory. The individual workmen in that factory were looked upon by the management as inspectors also and were entrusted with the responsibility of ensuring that their work was done properly. Materials and workmanship were generally inferior to British Standards, but one could not say that the aircraft made by the foreign factory were unsatisfactory. Some of these aircraft, which were put into service in 1924 and 1925, were still operating very satisfactorily under tropical conditions.

From a durability point of view in reference to composite aircraft, he would like to add that a Handley Page W.8.B. aeroplane, in the service of Imperial Airways, Limited, had completed a mileage of half a million, representing over five thousand flying hours over a period of six and a half years. Whether an all-metal aeroplane can create such a record of service without serious trouble from the effects of fatigue has yet to be proved.

Mr. C. H. LOWE-WYLDE: In connection with aircraft there was far too much construction and far too little production. The lay-out of aircraft factories varied widely, because many had developed from inadequate premises. The different types of machines produced at present required the application of different

methods, and a different sequence of construction, but it was time aircraft manufacture became a less specialised job, so that we could deal with the production side of the problem and endeavour to compete with foreign manufacturers. When aircraft manufacturers produced an experimental job there was far too much hand work employed, and they would not spend money on manufacturing jigs and appliances. If any operation had to be repeated a number of times it was wise to spend a few pounds on a jig, because a less skilled operator could then be employed on production and the chances of producing scrap were considerably reduced. As to the suggestion that the tube rib was economical, he held that it was costly to assemble, because one must use extraneous clips, etc. The pressed rib had advantages, but he suggested that the best combination was a pressed nose and a centre built-up portion of sheet material rolled or drawn to suitable sections. He asked what experience Mr. Sigrist had had of squeeze rivetting; he had seen it carried out on the Continent, and was convinced that it was the only cheap method of reliable rivetting. The suggestion that a man from the works or planning department should go to the drawing office to establish a liason was a good one, because frequently drawing office staffs had inadequate ideas of what their own factories could do efficiently. A man who understood the factory thoroughly could be very useful in the drawing office, for he could ensure that the drawing office staff were working along the lines best suited to the capacity and ability of the factory. Discussing the possibilities of meeting the demands of the industry at a time of national emergency, he said the position with regard to duralumin was very unsatisfactory, because only one concern was manufacturing it in this country. On the Continent there were more concerns producing it, and the Continental manufacturers consequently knew more about the material. Here more was known about steel, and in developing all-metal aircraft the use of steel should be developed. With regard to inspection, he said that the maximum error allowable in any part must be stated definitely, so that the inspector would have no discretionary power, but must either pass or reject a part; then a representative of the design department could examine parts rejected by the inspector and decide whether they be finally scrapped. He urged that there should not be too much insistence upon all-metal construction, because some parts could be made better of timber than of metal. For instance, he did not consider that a metal rib was so simple, efficient and cheap as a wooden rib, and we ought to use timber where it could be used most efficiently.

Squadron-Leader T. H. ENGLAND: He would like to say something in favour of the use of all-metal machines, particularly under tropical conditions. When he was serving with the Royal Air Force in the East, shiploads of aeroplanes of composite construction were sent out, and 95 per cent. of them were unserviceable. The American motor car manufacturers probably had had more experience than anybody in the world of the operation of motor cars under all conditions, and most modern American motor cars contained very little wood in their construction. Aeroplanes of the future must be made to last, and he believed the problem would be solved by building them of metal. With regard to Mr. Sigrist's statement that, roughly speaking, 45 per cent. of the personnel engaged in the construction of aircraft were skilled, 35 per cent. were semi-skilled, and 20 per cent. were unskilled, he asked how those percentages compared with the percentages obtained 10 or 12 years ago. He also asked for further information as to the behaviour of stove enamel and cellulose respectively, when applied to aircraft structure. It was his experience that cellulose flaked at high altitudes.

Mr. M. L. BRAMSON: He would like to make a strong protest against what appeared to be a cheerful assumption that another war would occur within a period which was likely to be of interest to present-day aircraft constructors.

Reply to Discussion

Mr. Sigrist, replying to the discussion, stated that the suggestion of employing as a liaison official a man from the works attached to the drawing office, instead of a drawing office man attached to the works, was quite a good one, but there was a difficulty in selecting the right man for this task. The job itself was not particularly onerous, but providing the official was conversant with the procedure in both departments it was not important as to which section he belonged.

He agreed with Mapor Wylie's remarks with regard to metal coverings. There might be scope for their use in civil aircraft, but the structure of military aircraft was constantly examined, and it was easier to patch or replace the fabric than it was to replace the metal covering.

On the subject of inspection, he stated that there were certain aspects of the question on which it was impossible to lay down hard and fast laws. He had an instance recently where a wooden spar was rejected owing to a warp of $\frac{1}{4}$in. in a 20ft. length simply because the inspector was not allowed sufficient discretionary powers.

He considered that the composite machine had not received sufficient consideration. The primary structure, *i.e.*, fuselage, spars, compression struts, etc., should be of metal, and the secondary structure, such as ribs and fairings, should be of wood. The cost of constructing such items in metal, apart from the difficulty of obtaining suitable material was out of all proportion to the benefits obtained. He did not consider that difficulty would occur in the tropics with carefully designed machines of composite construction. His experience was that in the tropics it was not the rib which was affected but the spar itself, the proportion of shrinkage being sufficient to loosen the rib and attachments. If a metal spar was used with a wooden rib there would be no possibility of an occurrence such as this.

He agreed with Mr. Savage's remarks that the A.I.D. authorities should empower the designer to alter his design within reason without reference to any other authority.

He had not available figures showing the percentages of skilled workers employed in aircraft construction ten years ago, but he considered that it was less than it was to-day, owing mainly to the fact that there was a considerable difference in the class of construction and not sufficient opportunity to introduce production methods, whereby unskilled labour could be utilised to a greater extent.

He had no knowledge of the flaking of cellulose coverings at altitude, but he considered that if properly applied it should possess the same wearing qualities as stoved enamel.

He agreed with Major Bulman's suggestion that consultations with the drop stamper and the foundry man should be of advantage, and invariably asked for criticism when submitting stamping and forging drawings to these concerns.

On the motion of the President, a hearty vote of thanks was accorded to Mr. Sigrist for his paper.

STEEL TUBES, TUBE MANIPULATION AND TUBULAR STRUCTURES FOR AIRCRAFT

BY

W. W. HACKETT

Lecture before the Manchester Branch, January 18th, 1929.

Weldless Steel Tubing for Aircraft

It is now more than ten years since, in conjunction with my brother, I gave a lecture to your Society in London on "Steel Tubes, Tube Manipulation and Tubular Structures for Aircraft." Since that time great progress has been made both in the production and manipulation of steel tubing. Things which were thought ten years ago to be impossible are now being done and it is, therefore, desirable that the paper should be brought up-to-date.

To commence the manufacture of a seamless steel tube a solid billet of steel is taken. The billet should be carefully examined for various faults and any laminations or surface defect removed by chipping, or else the outside of the billet should be turned all over.

The first operation is to pierce a hole. One way of doing this is by means of a hydraulic press, and another way is by means of a rotary piercing machine. In the latter method the billet, first centred with a large shallow hole, is heated to about 1,200° Centigrade and fed between rolls having a curved outline, and set at an angle which imparts a forward movement to the billet. As it is rotated great pressure is used which tends to cause the billet to open along its axis. The billet is forced against and over a pointed mandril held on the end of a stout rod which butts against a bracket at a distance of about 7 feet from the centre of the rolls. In the method in vogue a number of years ago the billet was then taken to a machine which was provided with upper and lower rolls having semi-circular grooves of various radii, and by a series of operations rolled into a tube of the required size. The tube was passed over mandrils to give the required thickness.

A quicker process used to-day is pilgering. This is largely used for the production of many classes of steel tubing, and is a quicker process because a heavy reduction can be carried out by the one operation. The pilgerer consists of two rolls, part of the periphery in each roll is missing, while the remaining working surface in each is a tapered groove. The hot bloom is placed over the pilger mill or mandril and is fed into the pilger rolls, which are revolving in the opposite direction to that in which the bloom is being fed. The rolls receive a portion of the bloom, and whilst the taper reduces that portion of the bloom, extending it forwards, it also forces the bloom as a whole backwards until the gap appears, when the pierced bloom is automatically fed forward again. This operation is repeated until the whole of the bloom has passed through the rolls. By means of the feed gear the bloom is turned through 90° at each forward feed to prevent the formation of fins. After the tube has completely passed through the rolls it is removed from the delivery table and cut to length, or it may be further extended by being passed through a series of rolls to reduce the outside diameter. This method, while being quick, is also good for the tubing as it is a forging operation carried out with rolls. The rolls, however, must be carefully made if a perfect tube is to be produced.

After the hollow bloom has been formed by the different operations just shown, the material then goes into the cold drawing mills and the first operation is that known as "tagging," which is reducing the ends of the blooms to allow them to be held by the grips in the dog. There are two methods in general use for forming the tag, one being by rolling and the other by means of a power forging hammer. The tube in the drawing operation to follow will be pulled through the die and over the mandril by means of the tag which is formed. A small hole is put into the tube near the tag in order to allow the proper pickling and swilling of the tube. After being tagged the tube is annealed, pickled in a bath of acid to eliminate scale, and then well swilled in clean water. Following this the tube is dried and then immersed in a solution of soap, or oil, or some other suitable lubricant, and it is then ready for the drawing operation.

There are two methods of cold drawing in general use, one is to draw down the outside diameter of the tube upon a long bar of uniform diameter, the tube and mandril passing through the die together. The bar is of uniform diameter and often precision ground. The tube after this operation is firmly fixed to the bar and has to be put through what is termed a reeling machine (which is similar to that used in the rotary piercing operation), before the mandril can be extracted from the tube. In this method of drawing the tube is put on to a bar, which must of necessity be smaller than the bore of the tube to be drawn. The tube is gripped on the tag by means of dog jaws sliding on inclined planes. The dog is moved along the draw-bench by hooks which are dropped into the links of an endless chain. The chains move at a speed of from 12 to 35 feet per minute, according to the class of material to be drawn. A chrome nickel steel tube or steel of the stainless variety has to be drawn through at the slowest possible speed, but the milder steel tubing can be drawn at higher speeds. This process of cold drawing permits of a greater reduction of wall thickness at each draw than that which can be obtained by the next process I shall describe, which is known as "plug" drawing, but it is harsher on the material and the expanding of the tube (already hardened by drawing) to allow the mandril to be extracted, sometimes causes splits and fractures, unless the reeling operation is very carefully performed. The appearance of the material after the reeling operation is often superior to that of a tube which is plug drawn.

The method known as "plug drawing" is more usually adopted and in this case a short hardened mandril is screwed into one end of a long bar. The bar is screwed on the other end into a larger piece of steel known as the back sleeve, which is screwed and fitted with a nut at either end. The sleeve has an endwise movement of about $\frac{1}{16}$in. in the back casting of the draw-bench. The nut at the back is used for the purpose of adjusting the position of the mandril in relation to the die. The tube is threaded over the mandril and the tag is passed through the die which rests against the die plate. Immediately the tube is gripped by the dog it commences to move, the mandril at the same time being pulled forward by the tube drawer by means of a rope or chain. A reduction in gauge thickness and diameter with a corresponding increase in length is the result. The usual reduction by this method is about a gauge and a half per draw on a low carbon steel tube, but considerably less than this on the harder grades. The operation of cold drawing hardens the tube to quite a large extent and subsequent annealing is necessary.

From time to time different schemes for cutting out the annealing operations have been tried. It has been found that the coating of tubes by lead has allowed as many as six draws to be made without any intermediate annealings, but the experiments we have carried out on tubing thus treated show that the tubing is in a very unreliable condition as a consequence. It is true some of the tensiles have been high, but there has been a brittleness about the tubing that is not present where annealings are given after each drawing operation. Some

people contend that a full normalising will restore the material, but in trying material so treated in some of the different manipulating processes we have found that this material never behaves so well as the ordinary tubing we supply.

The aircraft industry is repeatedly calling for lighter gauge tubing than it was thought possible to obtain a few years ago. The difficulty, however, in drawing these light gauge tubes is with the larger diameters, but we are experimenting to see if lighter tubes in the larger diameter can be obtained. We have produced tubes .004in. thick in sizes about 5/8in. diameter and have formed these into different sections, but when we have produced tubes of 3in. × 22 gauge thick we have experienced more trouble because of the ovalisation that takes place in the straightening operations. A tube as it comes off the draw-bench is never straight and the straightening operation, however carefully it is done, tends to alter the shape of the tube. The same effect occurs if a straight tube is bent; there is also, unless a mandril or some filling is inserted into the tube, going to be an ovaling of the tube in bending. Knowing as we do, however, the call for lighter tubes, we are trying to find a way out of our difficulties and hope to be able more satisfactorily to meet the needs of the aircraft trade in this respect in the future.

No doubt most of those present will be conversant with the different Air Board specifications for steel tubing. There has recently, however, been more attention given to steels that can be safely used for welded structures. In 1926 we carried out welding tests on steels having high manganese contents and very satisfactory results were obtained.

Specification D.T.D. 41 was the first specification for welded tubes and the carbon content in this case was to be .12 to .18 per cent. The minimum tensile strength of the tubes in the blued condition was:—

Yield 28 tons ... ... Break 30 tons.
And after welding, yield 17 tons ... Break 24 tons.

This class of steel is quite satisfactory in structures subjected to fairly low stresses, but a demand is growing for thinner gauge tubes which naturally means higher tensile strength, especially after welding.

To obtain these higher tensile figures a steel was produced having a maximum carbon content of .25 per cent. and a maximum manganese content of 1.5 per cent. Many experiments were made with this steel and it was found that tubes could be produced satisfactorily having, in the blued state, a yield of 35 tons and an ultimate of 40 tons per square inch. After welding, the minimum values for yield and ultimate were 25 tons and 35 tons respectively.

There was a wish, however, to replace the old T.5 specification with one suitable for welding. Consequently specification D.T.D. 89 was produced, having a chemical composition as indicated above. The yield and ultimate figures of blued tubes, however, were raised to those of specification T.5, namely, yield 40 and ultimate 45 tons. This, in the writer's opinion was too high a result to obtain from steel to this analysis without excessive drawing, and one was not likely to get the flattening test required in the specification. Furthermore, it was not possible to produce non-circular sections to this high tensile strength. To meet these cases the chemical composition of the steel was raised to permit a carbon content of .30 per cent. instead of .25 per cent. and the specification has been put under two headings, D.T.D. 113 (which covers circular tubes under $\frac{1}{2}$in. and all non-circular sections and requires specification T.1 tensile figures, namely, 30 tons yield and 35 tons ultimate), and D.T.D. 89A covering all tubes outside D.T.D. 113 and requiring specification T.5 tensile figures, namely, 40 tons yield and 45 tons ultimate). In each case the tensile strengths after welding are the same, the yield being 25 tons and the ultimate 30 tons per square inch.

To give the strength specified in the D.T.D. 89 specification a very hard draw is necessary to obtain the required result.

During my different visits to the U.S.A. I have found an increasing use of chrome molybdenum tubing in welded structures where extra strength has been required, and comparative tests have been carried out to see whether it is as good, or better, than the material used in this country. The specification of chrome molybdenum steel used is approximately as follows:—

Carbon	·3%
Chromium	1%
Molybdenum	·2%

We have made many tensile tests on butt welded joints with this steel and the results have shown that the ultimate strength after welding is invariably as high as that of the tubing in its original state. Fracture always takes place at a point about ½in. from the weld and never through the weld. Comparative tests between chrome molybdenum steel and D.T.D. 89 steel have been made both in tension and when subjected to alternating stresses and the chrome molybdenum steel has given better results than D.T.D. 89 steel.

FIRST SERIES OF TESTS.

	As drawn.			Blued at 450°C.		
	Yield.	Break.	Elong. 2in.	Yield.	Break.	Elong. 2in.
Chrome molybdenum ...	39	43	—	42	46	14%
D.T.D. 89	35	40	14%	37	43	18%

BUTT WELD TESTS.

	Yield.	Break.	Elong. 2in. over break.	
Chrome molybdenum	41·9	46·9	3%	Broke ½in. from weld.
	41·0	45·5	3%	,, ,,
D.T.D. 89 steel ...	25·75	36.8	6%	Broke ⅜in. from weld.
	26.0	36.2	5%	Broke ½in. from weld.

ALTERNATING STRESS TESTS,

Stressed to 16 tons per square inch at welds and 1,140 alternations per minute.

Chrome molybdenum ...	(1) Broke at	268,800 alternations.
	(2) ,,	229,600 ,,
	Average ...	249,200 ,,
D.T.D. 89 steel	(1) Broke at	117,600 ,,
	(2) ,,	108,640 ,,
	Average ...	113,120 ,,

Another series of tests made on a different supply of chrome molybdenum steel gave the following results:—

As drawn yield 45 break 48.0 elong. in 2in. 13%
Welded ... ,, 40 ,, 45.0 ,, 4%
Fatigue test, 16 tons fibre stress.
Average result, 385,700 alternations.

Here it might be mentioned that samples of tube in D.T.D. 41 steel, giving a yield of 20 tons and an ultimate of 30 tons per square inch after welding, collapsed immediately the load was applied, when subjected to the alternating stress tests described above.

Experiments have been made, and are still being made, with a type of steel containing approximately .30 per cent. carbon and .50 per cent. chromium. Tensile tests made on butt welds, welded with iron wire, have given the following results :—

	(1)	(2)
Yield	32.7	30.6
Break	47.4	46.8
Elong. 2in. over weld ...	10%	10%

In each case the fracture occurred away from the weld. In the " as drawn " condition, the steel had a yield of 45.3 tons per square inch and an ultimate of 49.3 tons per square inch.

A series of tests are now in progress in which further comparisons are being made between these high tensile welding steels. The low chrome steel, which has an ultimate tensile strength in the blued condition of 52 tons per square inch, gives the following results when welded :—

	Yield.	Break.	Elong. in 2in.
(1)	29.75	41.7	7%
(2)	29.4	40.65	9%
(3)	31.2	41.9	7%

The fatigue strength of this material appears to be very good but, as yet, not enough tests have been made to give comparisons.

A further example of the advantages in tensile strength which these alloy steels, containing percentages of chromium and molybdenum, possess over plain carbon steels when subjected to local heating, is illustrated by the results given below of various tests made on brazed joints. These tests give comparisons of alternating stress tests on tubes made from .35 per cent. carbon steel, specification T.1 quality, low chrome steel and chrome molybdenum steel, brazed with lugs and subjected to an alternating stress of 16 tons per square inch, at a rate of 400 alternations per minute with a shock of 36 inch pounds each 24 revolutions.

.35 per cent. carbon T.1 steel broke at ...	15,802	alternations.
Low chrome steel broke at	62,240	,,
Chrome molybdenum steel broke at	122,434	,,

A further series of tests made on similar tubes, but stressed to 18 tons per square inch at the brazed lugs, gave the following results :—

.35 per cent. carbon T.1 steel broke at ...	7,143	alternations.
Low chrome steel broke at	19,155	,,
Chrome molybdenum steel broke at	88,984	,,

Further Brazed Tests on Chrome Molybdenum " A " Quality and " K " Quality Butts

For these tests 1¼in. × 19/22 gauge butted tubes were used in " A " (as T.1), " K " (as T.5) and chrome molybdenum steel. The tubes were brazed into lugs and were run at a speed of 710 revolutions per minute.

STRESS AT LUG,
16 tons per square inch.

" A " quality broke at	9,940	revs.
" K " quality broke at	19,880	,,
Chrome molybdenum broke at	35,500	,,

Further tests were carried out on similar tubes, but with a lower stress at the lug, namely :—

STRESS AT LUG,
10.6 tons per square inch.

"A" quality	(1) Broke at ...	106,500	revs.
	(2) ,, ...	276,900	,,
	Average result	191,700	,,
"K" quality	(1) Broke at ...	205,900	,,
	(2) ,, ...	276,900	,,
	Average result	241,400	,,
Chrome molybdenum	(1) Broke at ...	589,300	,,
	(2) ,, ...	2,715,750	,,
	Average result	1,652,525	,,

From these figures it will be seen that the lower chrome molybdenum figure is five times that of the "A" quality and nearly three times that of the "K" quality, while the higher chrome molybdenum figure is ten times those of both "A" and "K" qualities. The average figures show the chrome molybdenum to be over eight times as strong as the T.1 quality, and seven times as strong as the T.5 quality.

The big difference in the results obtained from the chrome molybdenum tests is obviously due to a variation in the brazing temperature. For increasing temperatures over 850°C., the yield point curve of this steel rises rapidly and high brazing temperatures, which if used on plain carbon steels, would most probably cause failure through overheating, would actually give stronger joints in the chrome molybdenum steel.

Tests have been made on brazed joints in these three qualities of steel, run at a lower speed of 400 revolutions per minute, with a stress at the joint of 16 tons per square inch. Also a shock test was applied consisting of a 12lb. blow, with a 3in. fall, falling on the tube under test.

The results are below:—

"A" quality	(1) Broke at ...	16,882
	(2) ,, ...	14,772
	Average result	15,802
"K" quality	(1) Broke at ...	23,476
	(2) ,, ...	16,992
	Average result	20,234
Chrome molybdenum	(1) Broke at ...	134,734
	(2) ,, ...	110,134
	Average result	122,434

Although these tests were carried out under different conditions from those described previously, the average results give practically identical proportions, namely, the chrome molybdenum eight times the T.1 quality and six times the T.5 quality.

About three years ago a series of tests were carried out on welded test pieces of chrome molybdenum steel tubing, three being welded with iron wire and three with strips cut from chrome molybdenum tubing. The method of test was as those before mentioned with a fibre stress of 16 tons per square inch at the joints. The speed of running was 400 revolutions per minute, one blow being given every 24 revolutions. Those welded with iron wire ran for 64,431, 49,537 and 56,984 revolutions, and those welded with chrome molybdenum strip 63,059, 60,872 and 61,920 revolutions before breaking.

In no case where we have tested out this class of steel tubing against that in general use in this country have we had any result that has failed to prove its superiority.

Chrome Nickel Steel Tubes

There is no doubt that the advent of aeroplanes and airships has given rise to a demand for a higher class of steel tubing than was ever thought of before, and tubing which was looked upon as being quite satisfactory a few years ago would not come up to the standard required to-day.

When chrome nickel steel tubes were first called for they proved very troublesome to manufacture, but the difficulties have now been overcome and this steel, used as an axle, seems to be giving every satisfaction and, in the writer's opinion, is much better for this work than the chrome molybdenum axle used in the U.S.A.

A typical analysis of chrome nickel steel is as follows:—

Carbon	0.3%
Silicon	0.16%
Sulphur	0.03%
Phosphorus	0.03%
Manganese	0.45%
Chromium	1.10%
Nickel	4.00%

Such a steel when air hardened has an ultimate tensile stress of about 100 tons, but a low elastic limit to a maximum value of about 70 tons. Tempering tends to raise the yield point and at the same time to slightly reduce the ultimate stress.

A typical analysis of the chrome molybdenum steel, as used in the U.S.A., is as follows:—

Carbon	0.3%
Manganese	0.480%
Silicon	0.15%
Sulphur	0.02%
Phosphorus	0.025%
Chromium	1.00%
Molybdenum	0.25%

This steel, when normalised after drawing, has a yield of about 40 tons per square inch and an ultimate strength of about 49 tons per square inch on an average. When quenched in water it has a yield of about 70 tons per square inch and an ultimate strength of about 90 tons per square inch.

You will, therefore, see that as regards aeroplane axles, the British product seems to be superior to that used in the U.S.A.

During my visit to the Californian coast at the beginning of last year I found that heavy gauge tubes were tapered by turning on the outside. In one factory these were being turned from eight gauge at one end to 16 gauge at the other end. This is not an ideal method of thinning a tube, as it is impossible to get

a tube straight enough for this operation to be performed without a large degree of eccentricity occurring. A suggestion was, therefore, put forward that we should draw these tapered axles for this particular company. This was agreed to, and a number of these axles are now being used with a taper drawn on the inside of the tube, the tube now being parallel outside and tapered from 8 gauge to 16 gauge. This may be of interest to the aeroplane trade in this country as it is possible to effect a saving in weight while retaining the strength at the vital part of the axle.

In the paper given in 1918 on aeroplane tubing, it was thought well to point out the serious effect of sulphuric or muriatic acid on hardened chrome nickel steel tubing. It has the effect of making the tubing exceedingly brittle.

I mention this again because I was asked to investigate an axle breakage at a factory in California. It was not one of our axles, but I was able to determine the cause. The tube had been pickled to ease the work of the polisher, and the "blueing" treatment recommended by me brought back a brittle tube to its former ductile condition.

Whilst on the matter of chrome nickel steel tubing it may be of interest to know that we have carried out experiments with spars and other section tubes in chrome nickel steel to T.2 specification, and have effected the heat treatment by an electrical resistance method which has proved successful. The ordinary method of hardening by getting the material hot in a furnace and drawing out into the air causes a considerable warping of the tubes and it is extremely difficult to straighten a tube already hardened. By the electrical resistance method, however, the tubes come out much straighter and difficult sections can now be successfully produced giving over 90 tons tensile strength.

One of the drawbacks in connection with tubing to T.2 specification is the difficulty of drilling in its hardened condition, but there are parts where the high tensile will be an advantage if such parts have not to be machined, or where it would be possible to do the machining before the hardening operation takes place.

Section Tubes

The production of section tubes, such as streamline, oval, square, rectangular and fluted tubes, has received great attention during recent years, and many sections which tube makers would have hesitated to tackle ten years ago are now being produced.

The tube is always drawn to the necessary size and gauge in the round form and is then shaped by drawing through suitable dies or through rolls. The drawing of these tubes for the aircraft trade is often rendered more difficult by having to work to such specifications as T.5, T.1 and D.T.D.41. It is necessary to get such tubes to the required tensile strength in the round and then to form them to the desired shape. This can readily be done, so long as too sharp a corner is not expected on the sections. The designer sometimes asks for the streamline section to have a sharper trailing edge than is called for in the flattening test. In this case there is a chance of the tube fracturing in the forming operation, although drawn to pass the specification to which it is made.

The T.1 specification calls for a test which provides for the tube being flattened at the end, or at any point along the tube, by means of a few blows till the sides are three times the thickness of the metal apart.

I have brought with me sections of tubing which will prove that the forming to section is much more severe on the tubing that the test specified. This is especially so in the heavier gauges.

In the T.5 specification the test calls for a flattening, by the same method, till the sides are eight times the thickness of the metal apart. Unless, therefore,

something were done to retain the tensile and give greater ductility, streamline sections to specification T.5 would not be possible.

To produce the difficult section tubes to the specifications mentioned, it has been found necessary to use a higher class of steel, so that after the yield and ultimate required have been obtained there is sufficient ductility to enable the tube to be formed into the required section without fracture.

In the case of the T.1 specification a point higher carbon is often used, and as regards T.5 specification a steel with approximately 0.3 per cent. of nickel has been found to be admirable for the purpose.

Therefore, despite all difficulties, section tubes are repeatedly being made of difficult shapes, but giving a yield of 45 tons per square inch and an ultimate strength of 50 tons per square inch.

We can now produce in nickel steel any section illustrated in our catalogue, and in practically every case a minimum of 45 tons yield and 50 tons break can be obtained with excellent ductility. This is catered for in draft specification T.50, which gives alternative steels of D.T.D.91 and 3 per cent. nickel.

This steel is the best we can use for high tensiles, ductility, and as a high tensile manipulated steel for such items as tappet rods, aircraft spars and highly stressed structural work. Demands for this type of steel are increasing regularly.

I feel that I cannot conclude this lecture without dealing rather specially with the question of steel tubes for welding. This is an important matter, which calls for the earnest consideration of all engaged in the aircraft industry.

In the U.S.A. a large proportion of the aeroplanes have welded joints. There may be better methods of building if the plane is to be used for military purposes, but when building has to be done in competition for commercial purposes, welding does come out cheaper than many of the other methods of jointing.

If, therefore, the welding of joints is to be a common practice, it is surely right that research should be carried out to determine the best material for this work. Tubing with a 17 tons yield is obviously less valuable in aeroplane work than tubing with twice that yield, if the higher grade material can be satisfactorily welded. Tests have proved that this can be done.

Comparisons from a series of tests tend to show the value of different steels and the saving in weight which may be accomplished. Three tests carried out with 11 tons stress on material to D.T.D.41 specification broke after running 35,195 revs., 16,063 revs. and 20,236 revs., an average of 23,823 revolutions, whereas chrome molybdenum stressed to 10 tons per square inch broke at 64,431 revs. and 49,537 revs., an average of 56,983 revolutions. You will notice that the worst of the tests on the chrome molybdenum material was better than the best of the tests on the D.T.D.41 material.

The average on a further series of tests on chrome molybdenum material tested at 18 tons per square inch was 22,383 revolutions.

If, therefore, aeroplane constructors are interested enough to wish to try out this material for themselves, I will provide them with sufficient pieces of tubeing to enable them to do so.

During recent years aviation has made such great—I might even say such unexpected—strides forward that one cannot do otherwise than anticipate still further progress in the near future, but if this expected progress is to be realised the aeroplane constructor and the producer of his working material must move forward side by side.

As a manufacturer of the tubes which play an important part in modern aeroplane construction, I can confidently say that the tube makers are ready and willing to do their part in the experimental work which is so vitally necessary, if the aeroplane designer will only let them know what his objective is.

STAINLESS STEEL AND IRON

BY

W. HACKETT, JUNR.

Stainless Steel

During the last few years there has been a vast improvement in the manufacture and the manipulation of stainless steel tubes for both commercial and aircraft purposes.

Stainless steels are grouped into two classes, Austenitic and Martensitic. The Austenitic, which is mostly used, can be hardened only by cold working. Austenitic steels now produced are generally within the following analyses:—

Nickel	...	...	... 7 to 14%
Chromium	...	...	... 14 to 20%

To soften this type of steel it is necessary to heat to a much higher temperature than is usual with ordinary steels, and, according to the analyses, it has to be heated from 1,000°C. to 1,250°C. to fully soften. The best results are obtained when steel of this kind is quenched in water from its softening temperature, as the scale is then broken and pickling or de-scaling is quicker and easier.

There are many new stainless steels on the market, but all seem to follow the "Staybrite" analyses or the "Anka" type. The "Staybrite" is approximately 8 per cent. nickel and 18 per cent. chromium and is known as 8/18, while "Anka" is approximately 11 per cent. nickel and 15 per cent. chromium and is known as 12/15.

Great trouble has been experienced in the piercing and rolling of stainless steels, and it is mostly due to this, coupled with the high price of the raw material, that stainless tubing is so expensive. Before piercing, all billets must be turned to remove flaws, scale, and other defects, and carefully examined for any rolling or steel faults, and during pilgering and rolling extreme care is necessary in controlling the working temperature, which has a very critical range.

Rotary piercing does not seem to be a suitable operation for Austenitic steel, and at the present time solid billets have to be drilled or hot punched before the pilgering operation.

One method of making "Staybrite" tubing was by a hydraulic press operation which produced "cups" in the form of a short closed tube about 20in. long, 1¾in. outside diameter, and about ¼in. thick. These "cups" only weighed about 8lbs. each, and consequently it was only possible to make a very limited range of small sizes.

The drawing of stainless steels is very much more expensive than in the case of ordinary steels. Special reeler bars and drawing dies are necessary, and furnaces suitable for the high temperatures essential. The slowest possible drawing speeds are used, and great care and constant supervision are necessary in order to produce a good finished tube.

"The "Staybrite" class of steels, which include Hadfield's acid resisting, Vickers, Swedish 8/18, etc., have a scaling point of about 850°C., good welding properties, and are fairly ductile. When fully softened they have a yield point of about 17 tons per square inch with an ultimate of about 49 tons per square inch. The annealing temperature is between 1,100°C. and 1,200°C.

The only specifications covering tubing made from these steels are D.T.D.42 and D.T.D.57. The reason no tube specifications have been issued for this steel is due to "creep."

"Creep" is due to the limit of proportionality being considerably below the nominal yield point. The limit of proportionality of a fully softened "Staybrite" test piece giving a yield of 15 tons and ultimate of 50 tons is about 9 tons per square inch. This was discovered recently when "Staybrite" bolts elongated at a stress considerably below the yield point. This "creep" does not operate with stainless steel which is hard drawn and when the yield point is much closer to the ultimate. With a yield point of 50 tons per square inch and an ultimate of about 55, the limit of proportionality is very little less than in ordinary plain carbon steel.

This steel can be welded by the oxy-acetylene method and also electrically. The same material must be used as welding wire, to ensure the weld being as stainless as the material which is being welded.

Some steel makers insist that it is essential to fully soften and de-scale after welding; while others say that if the material being welded is fully softened before the welding operation, it is only necessary to de-scale. Under the circumstances it is perhaps safer to assume that both annealing and de-scaling are necessary. The de-scaling operation is merely a pickling in an acid containing about 50 per cent. muriatic acid and 5 per cent. nitric, with a good restrainer. This pickling or de-scaling quickly removes all scale and foreign matter on the surface. With very small tubes and where it is not possible to clean the inside by just de-scaling, it is necessary to sandblast and de-scale afterwards.

Like all other stainless steels, it is more resistant to corrosion after polishing, but after de-scaling it is almost as resistant. Wherever possible, stainless is supplied in the fully softened and de-scaled condition.

We have drawn tubes from this steel to 1/16in. outside diameter × 28 gauge, and have been experimenting with special tools to draw it even further. The largest size produced at present is about 3¼in., and between these sizes we can produce anything in the round tubing which has previously been produced to an ordinary steel specification.

The 12/15 is more suited for general purposes, being softer and more ductile and easier to manipulate. In the softened state it has a yield point of about 15 tons per square inch, and an ultimate of about 40 tons per square inch, with a limit of proportionality of about 9 tons per square inch. We have coils of this steel tubing here, .040in. outside diameter with a .020in. bore, and giving about 80 tons per square inch tensile. Tubing almost as small as this has been used in aircraft manufacture for small stainless tubular rivets

This steel is very good for flanging, flattening and bending, and can be drawn to T.5 (45 tons yield, 50 tons break) specification figures. Considerable quantities have been produced for aircraft work, and orders are steadily increasing. At present stainless steel tubing of this quality is released to a sheet or bar specification, and B.E.S.A. specification tensile figures.

Streamline sections have been made, and the only serious difficulties encountered have been with those sections having a radius at the tail less than that specified in the flattening test as given in Specification T.1.

Tubular rivets, engine bends and exhaust ring systems have been produced in these steels, and there seem to be great possibilities and scope for this type of steel.

Our range in this 12/15 steel is up to 3¼in. × 10g. covering all the sizes usually produced in other specifications.

Stainless Iron

This steel has a carbon content of about .1 per cent. and a chromium content of between 12 per cent. and 14 per cent. In the softened state it has a yield point of about 16 tons per square inch and an ultimate of about 30 tons per square inch.

When drawn and blued, it has strength equal to T.1 specification. In a small range of sizes it can be cold drawn and blued to the equivalent of T.5 specification, and when heat treated by air-hardening and tempering a tensile strength of about 75 tons per square inch can be obtained.

Three new specifications have recently been issued, D.T.D.97, 102 and 105, for this steel having the tensile properties equivalent to T.21, T.1 and T.5, respectively. The T.5 or D.T.D.105 may be obtained by cold drawing and blueing, or by air-hardening and tempering.

This material is not so stainless or resistant to corrosion as the " Staybrite " or " Anka " type of steel, although it is claimed to be quite good enough for seaplane work. Any rusting which takes place on this steel when in contact with sea-water is only a surface rusting, and stainless iron which has been in contact with sea-water for about twelve months loses very little of its strength.

Stainless iron can be welded, although the strength at the weld is very low, and, owing to the air-hardening of the weld, it is essential to anneal and pickle after the welding operation. To soften this steel it has to be heated to about 800°C. and cooled slowly. To harden, it has to be heated to about 900°C., cooled in the air, and subsequently tempered at about 300°C. We have drawn it down to $\frac{3}{8}$in. outside diameter, but we have not been successful with tubing smaller than this as the steel deteriorates by " sinking." In the larger sizes we have been able to produce all the sizes and gauges at present produced to specifications D.T.D.41 and T.1, and no difficulties should be experienced in the new specifications D.T.D.97, 102 and 105. The scaling point of this steel is about 800°C.

Brown-Bayley, of Sheffield, manufacture two steels called " Low-score " and " Two-score," the former containing about 1 per cent. nickel and 18 to 20 per cent. chromium, and the latter about 1.5 per cent. nickel and 18 to 20 per cent. chromium. These have been successfully drawn, but we have had no demand for this class of steel up to the present, although some people think that there is a great future for this material.

Altogether we have successfully drawn sixteen different types of stainless steel and stainless iron. It is obviously impossible to carry stocks of all these different steels, as comparatively small quantities are as yet required, but it has helped us to form an idea as to which give the best results.

Although stainless steel is as yet in its infancy it will sooner or later be called for in increasing quantities, and these experiments should be of service when the advantages of stainless steels are more fully realised.

Welding Tests on Chrome Molybdenum Tubing 1in. × 20G.

The following tests were carried out a short time after the foregoing paper had been read, but as they are of considerable interest in view of the opinions expressed by the writer, it has been thought desirable to complete the paper by including them.

The tests were made by twelve different welders, each welder doing two tests, one with iron wire and one with its own material.

Welded with iron wire.

	1.	2.	3.	4.	5.	6.
Yield tons per sq. in. ...	35.6	35.8	37.4	34.8	35.0	35.5
Break tons per sq. in.	42.3	41.5	41.0	43.0	41.3	41.8
Elong. in 2in.	5%	6%	7%	8%	6%	4%
Break from weld ...	½in.	½in.	⅝in.	½in.	½in.	¾in.

	7.	8.	9.	10.	11.	12.
Yield tons per sq. in. ...	32.1?	33.9	33.6	33.2	35.8	38.25
Break tons per sq. in.	41.3	37.5	42.0	42.2	45.1	42.8
Elong. in 2in.	6%	7%	12%	8%	5%	13%
Break from weld ...	½in.	Weld.	3in.	½in.	½in.	2½in.

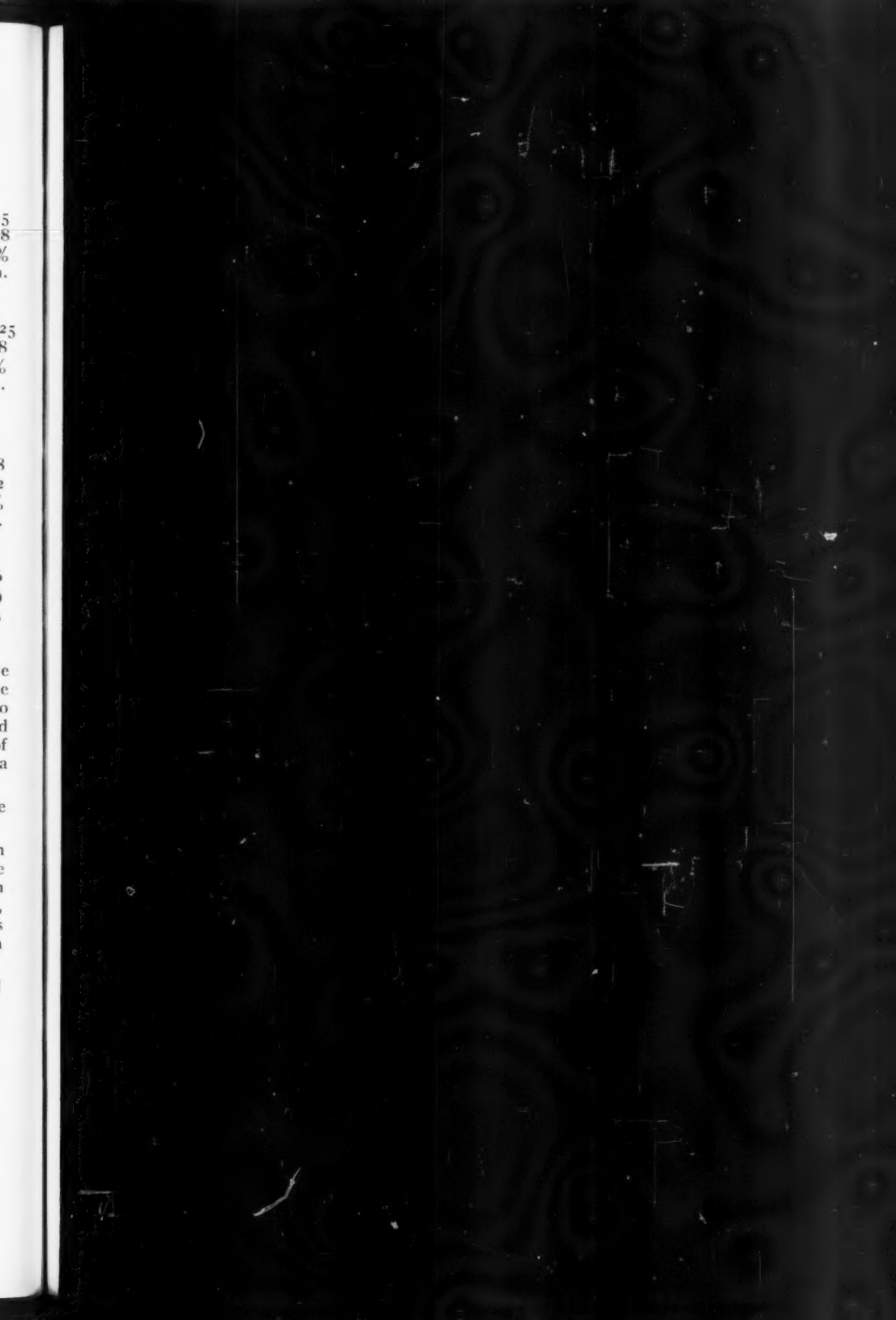
Welded with own material.

	1.	2.	3.	4.	5.	6.
Yield tons per sq. in ...	29.6	34.5	30.7	36.6	34.1	34.8
Break tons per sq. in.	41.1	40.0	41.0	43.3	42.0	43.2
Elong. in 2in.	7%	6%	6%	5%	6%	7%
Break from weld ...	½in.	½in.	½in.	½in.	⅝in.	½in.

	7.	8.	9.	10.	11.	12.
Yield tons per sq. in. ...	34.8	32.1	34.3	35.8	33.1	35.6
Break tons per sq. in.	42.4	40.9	41.5	44.9	40.9	43.9
Elong. in 2in.	6%	8%	8%	5%	6%	9%
Break from weld ...	½in.	Weld.	⅝in.	½in.	½in.	½in.

Twenty-two out of twenty-four tests broke away from the weld, and the two which broke through the weld were welded by the same girl, No. 8. The first of these, welded with iron wire, had not been welded right through, the two pieces being held together chiefly by the filling material. The second, welded with own material, showed signs of burning around the weld, but in spite of this a tensile force of 40 tons per square inch was necessary to cause a fracture.

The iron wire tests No. 9 and No. 12 are interesting, both breaking outside the zone affected by the heat during welding.

On the whole the tests are very uniform; with those welded with own material the yields are a little lower and the breaks slightly higher than in the case of those welded with iron wire. The average result welded with own material is yield 33.8, break 42.1, and for welding with iron wire, yield 35.1, break 41.8. Since the tensile strength of the material before welding was yield 35, break 42, these tests give further proof that the chrome molybdenum steel is practically as strong after welding as before.

It might be mentioned the worst results were expected from Nos. 4, 9 and 11, as these girls had little experience on this class of welding, but the results have shown that good welds can be made by welders with comparatively little experience.